AUSTRALIAN PORK LIMITED

Piggery Manure and Effluent Management and Reuse Guidelines

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Foreword

The Australian pork industry comprises many production systems including conventional, deep litter and outdoor. These systems generate significant amounts of liquid (effluent) and solid (manure) waste material, with the type of waste dependant on the production system housing, management and reuse opportunities.

Effluent and manure from piggeries has the potential to provide significant productivity and profitability opportunities for Australian producers. These materials are good fertilisers and soil conditioners on-site and also provide the potential to generate alternative income as a fertiliser for off-site use or generate alternative energy from Biogas. Poor practices associated with effluent and manure management, however, may cause a range of environmental issues such as nutrient overloading, run-off and amenity concerns such as odour generation.

Australian Pork Limited (APL) has significantly invested into the management and reuse of effluent, manure and sludge across all of the pork industry production systems. The research outcomes and other relevant technical information have been collated into the Piggery Manure and Effluent Management and Reuse Guidelines 2015. These guidelines expand on the framework for sustainable environmental management as set out in the National Environmental Guidelines for Piggeries 2010 revised and National Environmental Guidelines for Rotational outdoor Piggeries 2013. With specific emphasis on all things effluent and manure, these guidelines cover every aspect of effluent and solids management including collection, handling, treatment, reuse, monitoring, nutrient valuation and the duty of care when selling products from conventional, deep litter systems and rotational outdoor piggeries.

Piggery Manure and Effluent Reuse Glovebox Guide 2015, has been developed to compliment the guidelines that provides information on calculating nutrient concentrations, application rates and nutrient removal by crops or pastures.
These guidelines highlight the commitment of the Australian pork industry to ensure that resources are used and reused more efficiently and effectively to provide productivity and profitability benefits as well as reduce the environmental risks whilst enhancing the industry's overall environment credentials and performance.

Enzo Allara
Chairman
Australian Pork Limited

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Scope

The Piggery Manure and Effluent Management and Reuse Guidelines 2015 provide prospective and existing operators of Conventional, Deep litter and Outdoor production information to size, site, design, manage and reuse manure and effluent. The guidelines address the risks associated with effluent and manure management and focus on the potential benefits of best practise management including potential fertiliser and soil conditioning benefits and alternative income streams (off-site fertilisers and electricity generation from biogas systems).

The guidelines cover all aspects of effluent and manure management including collection, handling, treatment, reuse, monitoring, mortalities management, nutrient valuation and the duty of care when selling products.

An associated Piggery Manure and Effluent Reuse – A Glove Box Guide has been developed to compliment the guidelines that provides information on calculating nutrients, application rates and nutrient removal by crops or pastures.

Information has been tailored to the circumstances and conditions most commonly encountered on conventional, deep litter and outdoor systems. The authors acknowledge that these Guidelines may not cover all situations and therefore site specific circumstances must still be considered when applying these guidelines.

Adopting industry best practise for manure and effluent management will assist producers with meeting legislative requirements for waste management. However, it is important to note that legislative and planning requirements override these guidelines. Hence, these guidelines do not fully cover or address all of the requirements in each local government, state or territory and a development maybe assessed in a manner outside the scope contained in these guidelines.

Specific requirements pertaining to workplace health and safety are outside the scope of these guidelines. Producers need to understand and observe their obligations in relation to these matters.

Overview

These *Piggery Manure and Effluent Management and Reuse Guidelines* provide conventional, deep litter and rotational outdoor piggeries information relating to size, site, design, manage and reuse manure and effluent.

The document is made up of 12 parts and 3 appendices:

1 Introduction

2 Piggery Systems and Their Manure Streams

3 Cleaner Production

4 Objective of Piggery Manure and Effluent Management

5 Environmental Protection Principles for Manure and Effluent Management, Treatment and Reuse

6 Piggery Effluent – Management and Treatment

7 Management of Solid Manures

8 Reusing Manure and Effluent

9 Manure Management in Rotational Outdoor Piggeries

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1 Introduction

The Australian pork industry is committed to producing environmentally sustainable pork, which involves fostering a competitive pork industry while maintaining or enhancing natural resources and the environment for future generations. Sound management and reuse of effluent and manure are vital to meeting this commitment.

The National Environmental Guidelines for Piggeries (Tucker et al. 2010) (NEGP) provide a framework for the sustainable environmental management of piggeries. However, APL recognises that practical information on manure and effluent management is also needed. Through APL, the industry has invested significant research dollars into a range of projects that specifically investigated the effective management and reuse of manure, effluent and sludge. These guidelines collate these research findings into a single document addressing all aspects of manure and effluent management.

Responsible manure and effluent reuse can improve soil structure, build soil organic matter levels, improve rainfall infiltration and soil water holding capacity, enhance soil fertility, reduce erosivity, increase plant yields and reduce inorganic fertiliser costs. However, poor practices may cause a range of environmental and other concerns. These guidelines provide complete, practical information for sustainable management of manure, effluent and sludge. They describe the properties and management options for each manure stream. They also detail the many opportunities available for producers to enhance the environmental performance of their operation through the adoption of best practice effluent and manure reuse practices.

2 Piggery Systems and Their Manure Streams

2.1 Introduction

The main by-product of any piggery is manure. Manure, which includes faeces and urine, contains:

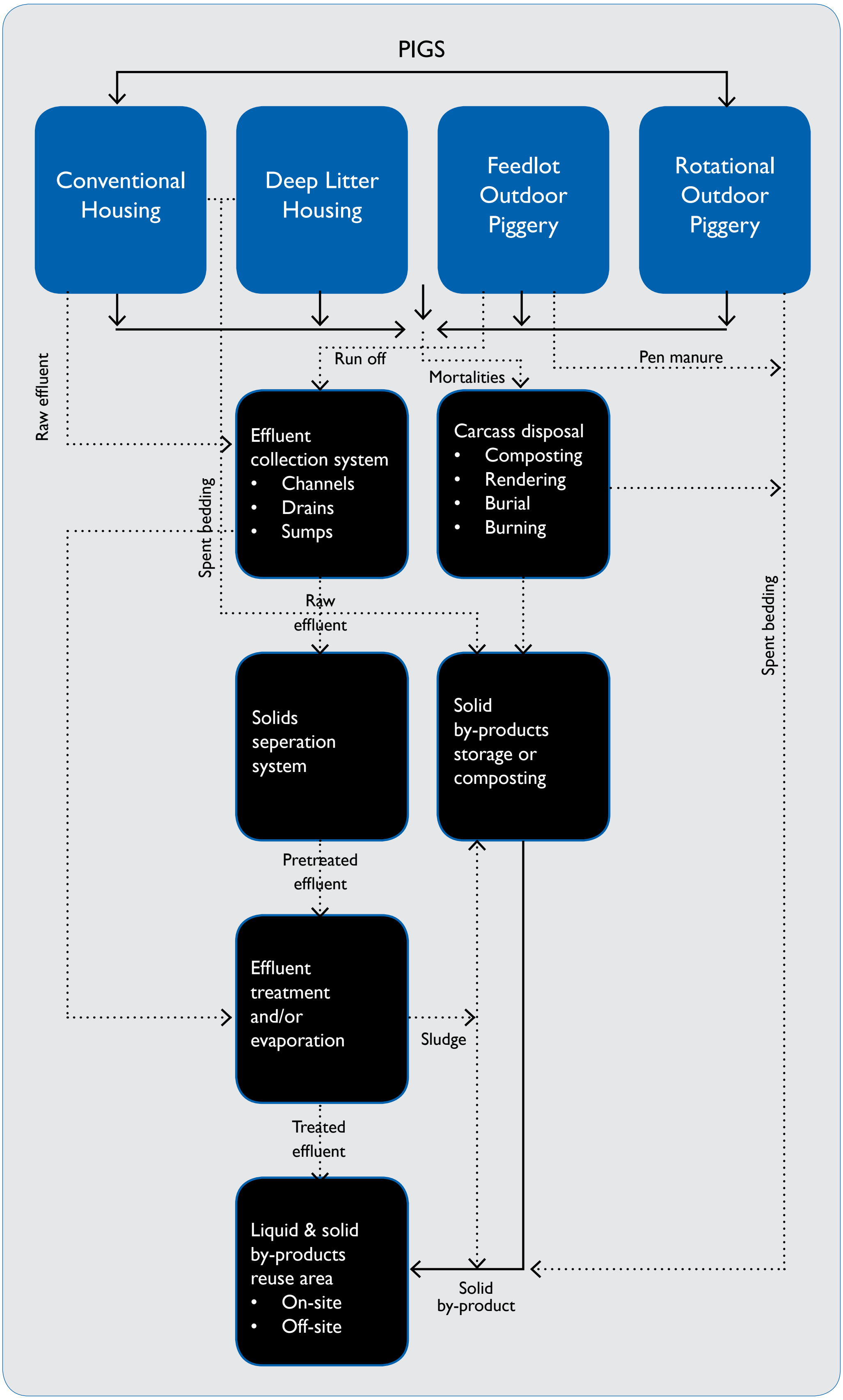
- Water – about 90% by weight
- Organic matter – made up of complex carbohydrates which consist mainly of carbon (C), hydrogen (H) and oxygen (O). In effluent treatment terms, organic matter can be referred to as biological/biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) or volatile solids (VS). When organic matter is digested, simpler compounds such as carbon dioxide (CO_2) and water (H_2O) are released. In these guidelines, the sizing of the treatment capacity of the effluent ponds is based on volatile solids loading rate.
- Nutrients – these include the macro-nutrients (nitrogen (N), phosphorus (P) and potassium (K)) and a range of minor nutrients and trace elements.
- Salts – most salt enters via the water supply, with some brought in with the feed.
- Microorganisms – including pathogens.

The type of piggery system affects the form in which manure is presented for treatment. The National Environmental Guidelines for Piggeries (NEGP) describe the following types of piggery operations:

- Conventional
- Deep litter
- Outdoor
  - Rotational outdoor
  - Feedlot outdoor.

Each of these systems produces different manure streams and uses different manure management methods. Mortalities also need to be managed at all piggeries. A summary of manure and mortalities management for each system is provided in the sections that follow and in Figure 1 which is taken from the NEGP.

FIGURE 1 **Piggery manure and effluent flow diagram**



2.2 Conventional Piggeries

Conventional piggeries accommodate pigs within sheds (Photograph 1). The flooring is usually partly or fully slatted and spilt feed and water, urine and faeces fall through the slats into concreted underfloor channels or pits. Usually the flooring is regularly hosed to dislodge dried manure. To remove effluent from the sheds the under-floor channels or pits are regularly flushed or drained. Sheds without slatted flooring usually include an open channel dunging area which is cleaned by flushing and/or hosing. Hence, the primary by-product from conventional piggeries is liquid effluent.

Photograph 1 Conventional housing

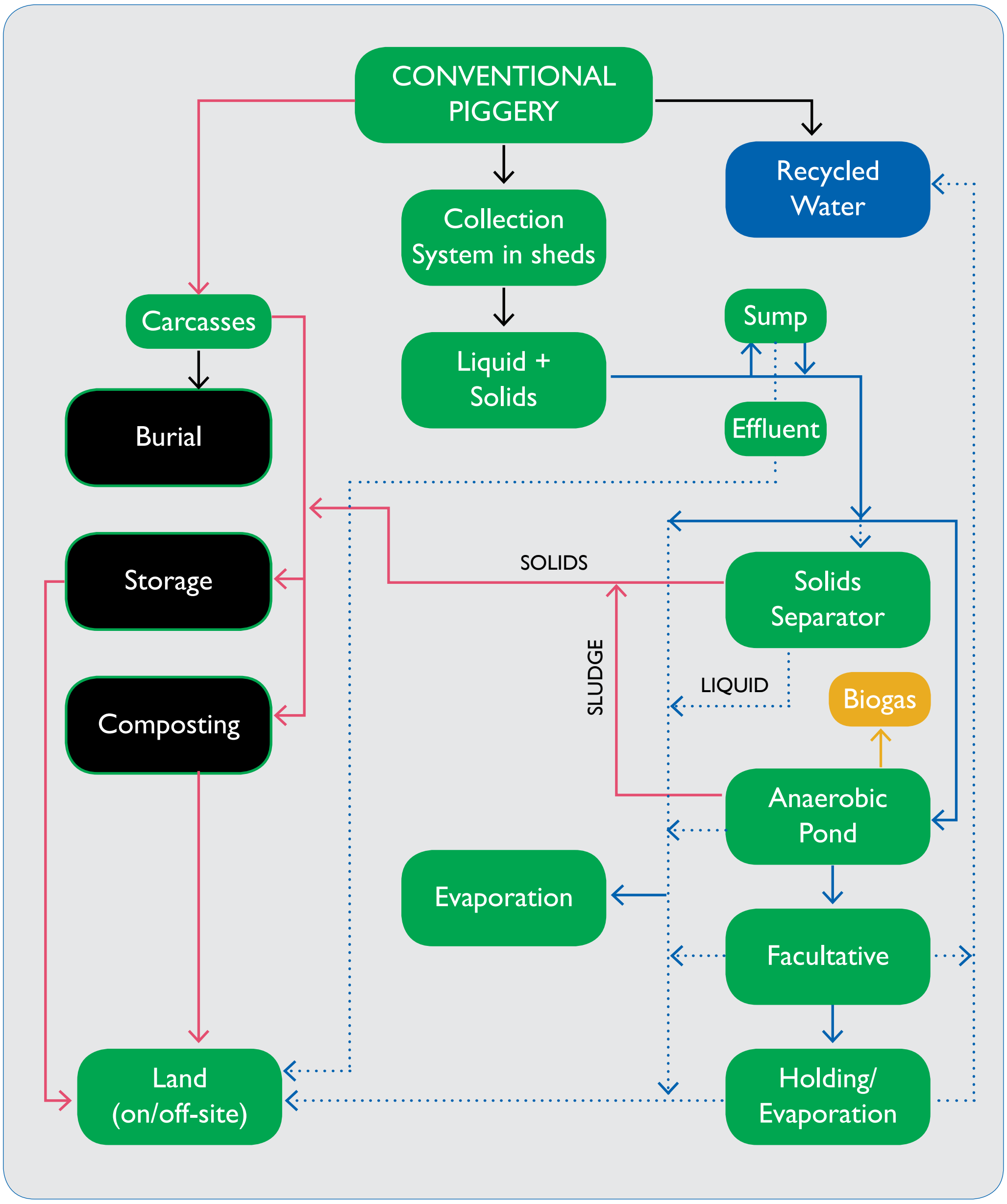
In some cases, the effluent is pre-treated by removing some of the solids. Most piggeries then use ponds to treat the liquid component before the effluent is irrigated or evaporated. However, some piggeries use SEPS (sedimentation and evaporation pond systems) in conjunction with holding ponds while some smaller operations capture the effluent in a sump and irrigate it directly. Even with pre-treatment, solids accumulate as sludge in the bottom of ponds, SEPS and sumps over time.

The by-products from these systems can include:

- Separated solids
- Effluent
- Sludge.

Figure 2 summarises the major by-product management options for conventional piggeries.

FIGURE 2 **By-product management options – conventional piggeries**



2.3 Deep Litter Piggeries

Deep litter piggeries typically house pigs in structures consisting of a series of hooped metal frames covered in a waterproof fabric, similar to the plastic greenhouses used in horticulture (Photograph 2). However, skillion roof sheds and converted conventional housing may also be used. Pigs are bedded on straw, sawdust, rice hulls or similar loose material that absorbs manure, eliminating the need to use water for cleaning. The bedding is topped up as needed to ensure there is a dry area for the pigs to lie on. The major by-product is spent bedding. This is generally removed and replaced when the batch of the pigs is removed, or on a regular basis.

Photograph 2 Deep litter housing

2.4 Rotational Outdoor Piggeries

In rotational outdoor piggeries, the pigs are kept in small paddocks with huts or other shelters (Photograph 3). The pigs are supplied with prepared feed, but can also forage. Rotational outdoor piggeries may be breeder units, grower units or farrow-to-finish units. The main by-product of these systems is the manure deposited by the pigs, although spent bedding from the huts or shelters is another by-product. The pigs tend to favour particular areas for dunging so active management is needed to ensure manure is spread evenly over the paddocks. The land use of the paddocks is a rotation starting with a pig phase and followed by crops and/or pastures and/or forage. The plants grown in the non-pig phase need to be harvested to remove the nutrients deposited in pig manure.

Photograph 3 Rotational outdoor piggery

2.5 Feedlot Outdoor Piggeries

Feedlot outdoor piggeries accommodate pigs in permanent outdoor pens, sometimes with huts or other shelter. The main by-product from these piggeries is nutrient-rich effluent generated from rainfall runoff from the pens. Feedlot outdoor piggeries must be located within a controlled drainage area (CDA) so that this effluent is kept separate from clean runoff from surrounding areas. Very small piggeries may be able to disperse the runoff on land below the piggery, assuming the site is suitable. However, the runoff is usually directed to a holding pond, sometimes via a settling device that removes some solids. Solids also accumulate in the pond as sludge.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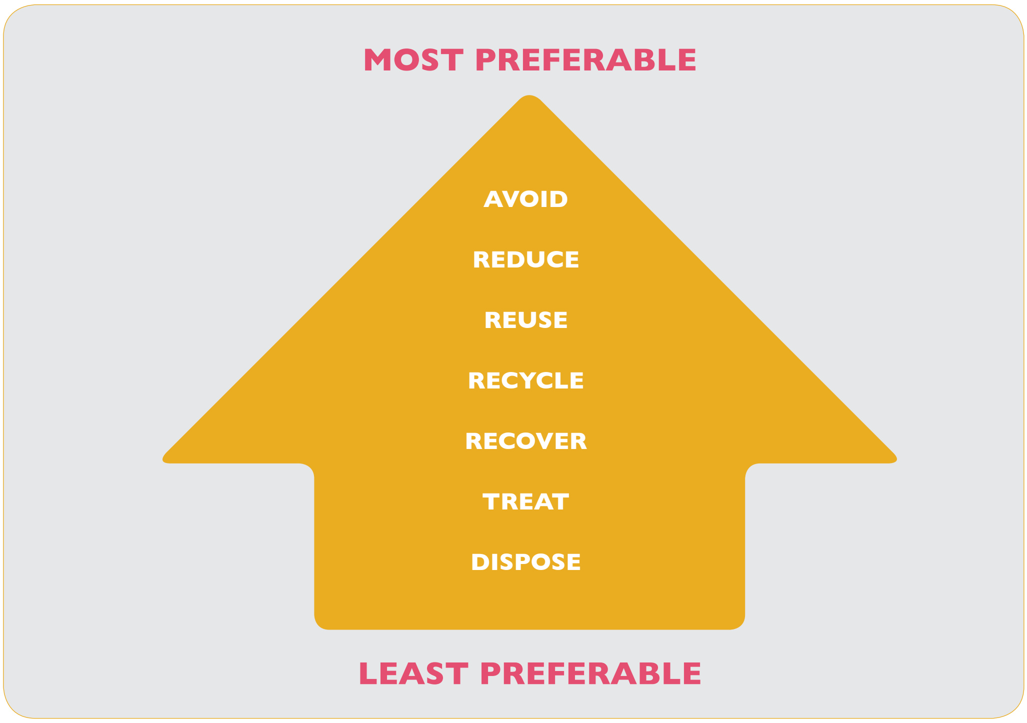
3 Cleaner Production

Cleaner production involves maximising productivity by minimising by-products and emissions. This involves following the management hierarchy shown in Figure 3.

FIGURE 3 By-product management hierarchy



There are a number of cleaner production opportunities at piggeries.

3.1 Feed Wastage Minimisation

Estimates of feed wastage at piggeries vary from 5% to 20% or more. A kilogram of spilt feed is equivalent to several kilograms of manure when added to a manure stream, since none of the energy, protein and nutrients in the feed have been digested. Minimising feed wastage makes economic and environmental sense; it improves productivity and reduces the potency of the manure stream.

3.2 Feed Digestibility

High levels of feed digestibility are necessary for efficient feed conversion and also reduce manure excretion rates.

3.3 Nutrient Minimisation

Reducing dietary nutrient levels and improving their availability to more closely match dietary requirements reduces nutrient excretion rates.

3.4 Salt Minimisation

Salt can be minimised by reducing the amount of salt added to the diet, using a low salinity water source and minimising water usage.

3.5 Water Use Reduction

As well as conserving a resource, reducing clean water usage reduces the volume of effluent for treatment and storage and usually improves the performance of solids separators. Good maintenance and prompt repair of water systems is essential in minimising water wastage. Installing well designed bowl or bite drinkers rather than push nipple drinkers reduces wastage. Installing thermostat-controls, and using appropriate settings, on spray or drip cooling systems ensures these are used when most needed. Using treated effluent to flush sheds saves water without reducing the total cleaning water volume. However, this may pose a number of issues. It doesn't reduce the quantity of organic matter for treatment. It may result in higher ammonia and odour levels in the sheds. Pathogens in the effluent may pose a risk to the pigs. Struvite formation in pipes and pumps may also arise.

3.6 Beneficial Reuse of Effluent and Manure

Effluent and manure can provide nutrients for use in cropping systems and also improve soil physical properties through the addition of organic matter (see Section 8).

4 Objective of Piggery Manure and Effluent Management

The primary objective of piggery manure and effluent management is to treat the organic matter and reuse the nutrients and organic matter they contain in a beneficial and ecologically sustainable manner. This involves managing dust, odour and gaseous releases that may affect community amenity and Greenhouse Gas (GHG) emissions; and nutrients that may adversely affect soils, water resources and flora and fauna.

4.1 Organic Matter Breakdown

Organic matter is broken down by microorganisms including bacteria, enzymes, and fungi. There is a vast range of microorganisms that can survive in very different environments. A primary grouping of microorganisms are anaerobic, facultative and aerobic. Anaerobic microorganisms thrive in conditions where there is no oxygen, while aerobic microorganisms need oxygen to survive. Facultative microorganisms can function in the presence or absence of oxygen.

As soon as manure is produced, microorganisms start the breakdown process. This continues in an ad-hoc manner if no specific effluent treatment system is used, or in a precise and optimal manner in a well-designed and managed liquid effluent treatment (liquid wastes) or manure composting system.

4.2 Managing Effluent Treatment

Uncontrolled breakdown occurs in manure slurries. Simple anaerobic ponds provide the next level of treatment where 60–90% of organic matter can be removed. More complex treatment systems such as anaerobic digesters can more completely breakdown organic matter. If organic matter is broken down anaerobically, the end products are mainly low odour methane (CH_4) and carbon dioxide (CO_2) but other (sometimes odorous) gases are produced. However, incomplete anaerobic digestion results in the release of acidic, odorous gases. If organic matter is broken down aerobically, more carbon dioxide and less methane is produced.

Most treatment systems allow the gases to escape to the atmosphere. However, methane is both a potential energy source and a GHG. Methane has about 25 times the global warming potential (GWP) of carbon dioxide. Covered ponds and other treatment systems can be designed to collect the methane produced by the anaerobic breakdown of piggery effluent. It can then be used as a source of heat and/or energy or flared.

4.3 Managing Manure Breakdown

Options for managing manure removed from pig housing range from storage in static piles (stockpiling or aging) through to active composting.

Manure stored in static piles may decompose aerobically or anaerobically, depending on its moisture content. Wet solids break down anaerobically, which can release strong odours. Drier manure decomposes aerobically, which is a low odour process. Adding bulky, dry substrates e.g. sawdust and/or turning the manure reduces the moisture content, although turning may temporarily increase odour levels. Manure that is very dry will produce dust, although this is rarely an issue providing the manure is left undisturbed.

Manure composting generally produces little odour. Maintaining a suitable moisture content and carbon to nitrogen ratio (C:N) optimises the process. Where moisture is a constraint, significant dust can be generated during turning and handling. This may compromise community amenity. It also slows the process rate.

4.4 Problems Resulting from Poor Manure and Effluent Management

The addition of organic matter and nutrients to Australian soils is usually beneficial but their entry to water resources (particularly N and P) is always detrimental. Organic matter and nutrients can enter waterways as runoff or eroded soil, and can leach into groundwater. Elevated soil nutrient levels may also kill native flora and encourage weed growth.

Salts can lead to the degradation of water resources and soils and impact plant growth. It is difficult to separate the nutrients in manure from the salts. When manure or effluent is spread on land, salts are also applied. Excess salt applications can cause the types of salinity problems common in southern inland Australia. Depending on the ratio of sodium (Na) to calcium (Ca) and magnesium (Mg) soil structural problems (sodicity, surface sealing) may eventuate. Salt is generally only a concern when effluent is reused. The salinity of the effluent is determined primarily by the salinity of the incoming water supply and the amount of recycling and evaporation of effluent.

Reuse areas must:

- Be well sited (with buffers to waterways);
- Have suitable soil properties to grow and harvest crops or pastures; and
- Be properly managed – nutrient loading rates must be matched to soil conditions and crop requirements, irrigations need to be managed to avert runoff and erosion.

5 Environmental Protection Principles for Manure and Effluent Management, Treatment and Reuse

Facilities used to treat and store manure and effluent need to be carefully sited and constructed with environmental protection in mind. Consider:

- Topography including slope (for drainage)
- Proximity to surface waters, particularly major water supplies which typically require an 800 m buffer
- Depth to groundwater. The depth to the water table from the excavated base elevation of compacted earthen drains and basins, ponds and solids storage areas should exceed 2 m at all times
- Soil type – all facilities that treat or store manure or effluent need to exclude extraneous stormwater runoff and have a low permeability base. DAFF (2009) provides a technical standard for clay lining and compaction of effluent ponds while DAFF (2011) provides a similar specification for constructing earthen pads (see Appendix 1: Pond and Pad Permeability Specifications)
- Area available – space is needed for possible future expansion of piggery and ponds and also to provide access for desludging and maintenance
- How the pond will be desludged. Narrow ponds can be desludged with a pump or vacuum tanker. Ponds that will be desludged with earthmoving equipment need to provide safe crest widths and wall slopes
- Proximity to neighbours and public areas and prevailing winds
- The requirements of the local authority and other relevant approved authorities.

Responsible reuse of treated manure and effluent can increase soil organic matter, enhance soil structure, improve rainfall infiltration and soil water holding capacity, enhance soil fertility, reduce erosion rates, increase plant yields and reduce inorganic fertiliser costs. However, poor practices may result in a range of environmental and other concerns. To prevent adverse environmental impacts:

- Spread the nutrients and water in manure and effluent at productive and sustainable rates
- Use application methods that promote even and controlled distribution and do not promote effluent drift (avoid high pressure guns) or runoff losses (only use surface application on sites with an even grade and suitable soil type and slope)
- Spread manure and effluent at suitable times and conditions – consider the weather, particularly prevailing wind direction and only irrigate effluent when the soil has a suitable moisture content and rain is not forecast

- Apply manure and effluent to crops at times when uptake is likely (e.g. just before sowing, during periods of active growth) to maximise uptake and minimise leaching losses
- Use secondary nutrient control measures to reduce stormwater runoff velocity and soil erosivity, and capture nutrients contained in runoff e.g. vegetative filter strips (VFS), terminal ponds, graded banks, groundcover and incorporation of solid manure.

6 Piggery Effluent – Management and Treatment

6.1 Introduction

The effluent from conventional pig sheds can contain manure, waste feed, water used for cleaning and cooling, spilt drinking water, detergents and disinfectants and traces of veterinary chemicals. The manure and waste feed contribute the organic matter, most of the nutrients and some salts. Water can also contribute a significant salt load.

Management and treatment of effluent involves collection (Section 6.2), sometimes solids separation (pre-treatment) (Section 6.3) and wastewater treatment and storage, generally using a pond-based system (Section 6.4). Good control of odour and vermin is an important part of effluent management and treatment (Section 6.5).

6.2 Effluent Collection Systems

Effluent collection from the sheds usually involves drains, flushing channels, static pits, pull plug pits, or some combination of these. Scraper systems are used by a small number of piggeries.

Most piggeries use flushing channels, pull plugs (particularly in southern Australia) or static pits to remove effluent from sheds.

6.2.1 Flushing Channels

Flushing channels are concrete channels that sit underneath slatted flooring within the sheds. Manure, waste feed, hosing water and drinking water wastage drop through the flooring and into these. Flushing channels are generally cleaned at least daily through a quick release of clean water or recycled treated effluent from flush tanks (see Photograph 4).

Most under-slat channels are formed from rectangular box drains. The channels are generally up to 50 m long with a 1% slope lengthwise to facilitate solids removal. Ideally these are up to 600 mm wide. If the channels are too wide the flow rate slows reducing cleaning effectiveness. Wider channels can be divided to overcome this. A flow velocity of 0.9 m/s with an initial flow depth of 75 mm and a flush duration of at least 10 seconds is needed to dislodge and transport solids. Some 700–1000 L of flush water is needed for each metre of drain width (Kruger et al. 1995).

Photograph 4 Flush tanks

6.2.2 Pull Plug Pits

Pull plug pits store effluent in small underfloor pits. The pits fill with shed hosing and spilt drinking water, manure and waste feed typically over a period of one to two weeks. They are then drained through a central gravity release pipe. The empty pit is partly refilled with clean water to prevent manure from sticking to the floor. Because no flushing water is used, pull plug pits use less water than conventional flushing systems.

Organic matter breaks down during pit storage, reducing the amount for later treatment. This is a disadvantage if the effluent will be used to produce biogas. Pulling the plugs more frequently can overcome this concern.

6.2.3 Static Pits

Static pits are found in some older sheds. These are under-floor channels, often with a 1% slope, with a sluice gate at one end (Photograph 5). Manure, waste feed and water from hosing and drinker wastage fall through slatted flooring into these pits or channels. The channel stores the effluent typically for one to two weeks (but sometimes longer) before the sluice gate is opened to release it. Static pits release odours and NH_3 as the manure and waste feed decompose. These can be partially refilled after releasing to prevent manure sticking to the floor. Nevertheless, solids often gradually accumulate in the base and need to be manually removed. However, they do use less water than flushing systems.

Photograph 5 Sluice gates on a static pit

6.2.4 Drains

Open drains are generally found only in grower and dry sow areas in older sheds. They are usually located within the pens. Open drains are typically 50–100 mm deep with a slope of 1%. Because pig activity in open drains dislodges some manure the average flushing depth can be reduced to 40 mm with a velocity of 0.6 m/s for 10 seconds. Hence, 400–600 L of flush water is needed for each metre of drain width. Open drains result in dirty pigs and pens and may also transmit disease along the shed (Kruger et al. 1995).

6.2.5 Manure Scrapers

A small number of Australian piggeries have installed manure scrapers in their under-floor channels. Rather than using flushing water, a blade pulled along the surface of the channel by steel cables pushes manure from the channels. Cable maintenance and manure odour levels can be issues for piggeries using these systems.

6.2.6 Pipes or Drains Ex-Sheds

Impervious pipes or drains should be used convey effluent from sheds to sumps, pre-treatment or effluent ponds. If pipes are used, sewage-class Poly Vinyl Chloride (PVC) or High Density Poly Ethylene (HDPE) pipes at least 150 mm in diameter are recommended. If effluent is to be transferred under gravity flow, sufficient slope (minimum 2%) must be provided to move the effluent. Drains must be designed to exclude stormwater runoff from surrounding areas.

6.2.7 Sumps

At some piggeries, effluent is directed from the flush channels or pits into a sump so the flow rate to a mechanical solids separator can be managed. Some smaller operations also use sumps to regulate the flow of effluent directly to an irrigator. Photograph 6 shows an effluent collection sump.

Generally the sump is an in-ground tank sized to store at least a day's effluent production. The sump needs to be made out of strong, corrosion resistant material like concrete, fibreglass or stainless steel. It is a good idea to install a screen on the inlet channel to remove large foreign bodies that could block pumps. Generally the effluent in the sump is kept mixed using a horizontal bar or propeller mixer to keep solids in solution and prevent crust formation. Stormwater runoff from surrounding areas should be excluded from sumps.

Photograph 6 Effluent collection sump

6.3 Solids Separation

At some piggeries, solids are separated from the effluent stream ahead of either direct irrigation or pond treatment. The benefits of solids separation prior to pond treatment may include:

- Removal of large particles that can block irrigation equipment
- Reduction in organic load to the pond (not beneficial if the system involves biogas collection)
- Improved biological degradation in the pond due to removal of some non-biodegradable solids (removal of coarse materials and barley husks is advantageous for Covered Anaerobic Ponds (CAPs))
- Reduced sludge accumulation rate because less solids enter the pond; desludging is less frequent
- Reduction in required pond capacity per Standard Pig Unit (SPU)
- Reduced pond surface area and hence reduced odour emissions
- Smaller reuse areas needed for sustainable reuse of nutrients in the treated effluent, although the nutrients in the removed solids will still need to be sustainably reused.

Screens, presses and settling devices are the most common solids separation mechanisms used at Australian piggeries. Adoption of alternative mechanical devices and tertiary treatment has been hindered by relatively high costs, maintenance requirements, labour requirements, complexity of design and operation and performance. Table 1 presents data on the performance and relative capital and operating cost range (e.g. low, medium, high for a range of various solids separators).

Figure 4 provides a summary of the properties of solids piggery effluent and solids removal systems. Management of separated solids is detailed in Section 7.2.1.

6.3.1 Screens

Screens are usually formed from steel wedge wire mesh that provides apertures of 0.1–1.5 mm or larger. They separate solids from liquid on the basis of particle size and shape. Screen efficiency depends upon the mesh size; the area of the screen; the flow rate and the solids percentage of the effluent.

The most common screen is the stationary run-down screen, sometimes called a stationary incline screen or static screen (see Photograph 7). The screen is installed after the sump so that effluent can be supplied at a consistent flow-rate. The larger solids are trapped by the screen. These slide down the screen and into a storage area. The liquid and very fine particles pass through the screen where they are collected. Usually the screened liquid is directed to an anaerobic pond or storage. With use, a biomass film rapidly develops across the surface of the screen, blinding or blocking the screen particularly if the screen is fine. This significantly reduces its usefulness. Relatively fine screens (e.g. 1 mm) generally remove more solids, particularly volatile solids (VS). However, very fine screens block more quickly, reducing effectiveness. Regular and frequent cleaning with a steel brush is needed.

Photograph 7 Stationery rundown screen at piggery

A vibrating screen is similar to a run-down screen except that the screen vibrates rapidly. Because of the moving parts, these screens have higher maintenance and power requirements than stationary run-down screens. Although the vibrating helps to prevent blocking, regular cleaning is still needed.

A rotating or centrifugal screen comprises a spinning cylindrical screen. The effluent is applied to the inner surface of the screen, which resembles the inside of a clothes drier. The solids remain on the surface of the screen and the liquid moves through the screen. A scraper can be used to remove solids collecting on the screen.

6.3.2 Presses

Most presses used in Australian piggeries are screw presses. Belt and rotating screen presses are alternatives. A screw press consists of a cylindrical screen with a screw-conveyor in the centre. The conveyor presses the solids against a screen to remove moisture. The conveyor also moves the solids through the press to a collection area. Photograph 8 shows a screw press separator installed at a piggery.

Screw press separators are more expensive than rundown screens. However, they are relatively simple devices with low operating costs and maintenance requirements. They also produce drier, more manageable solids than screens.

Photograph 8 Screw press separator

6.3.3 Settling

Settling devices use the density differences between solids and the liquid to separate the two. Settling or sedimentation basins or tanks, or sedimentation and evaporation pond systems (SEPS) are types of settling devices. Settling has the potential to remove more solids than most alternatives (over 50%), but requires more management. There is potential for significant odours if settling devices are not regularly cleaned. For that reason, batch-operated sedimentation tanks, or concreted trafficable sedimentation basins, are sometimes recommended.

Settling basins should be shallow (0.3–1.0 m deep), long, wide and free draining. The flow rate through these should be less than 0.3 m/s and they should detain the effluent for at least 20–30 minutes. Concreting the floor and walls makes these trafficable and easy to clean, although this adds to the cost.

SEPS are a form of settling basin (see Photograph 9). They were originally developed to avoid the difficult problem of removing sludge from large, deep conventional ponds. They typically consist of two or three parallel earthen channels that are narrow, shallow and trafficable. The channels, which are laid out on the contour, are typically about 6–10 m wide at the base, 20 m wide at top water level and 0.8 m deep. The shallow depth promotes quick drying, although a crust forms on the surface. Being shallow, they are relatively cheap to build. Each pan is used independently; when one is filling, another is drying. Liquid is drawn from the end most distant from the entry point and directed into storage dams. As the sludge in the SEP dries, a crust forms inhibiting further drying; breaking the crust enhances drying. When the sludge becomes sufficiently dry, the sludge can be removed using a blade, front-end loader and truck. Detailed information on design and construction requirements for SEPS is provided in Watts et al. (2002b).

Photograph 9 SEPS

6.3.4 Other Solids Separators

Other solids separators that have been used at Australian piggeries include:

- Cyclones: cone-shaped devices that sit vertically with the apex closest to the ground. Liquids swirl to the top and exits via a pipe while solids drop to the base
- Centrifuges: these use a spinning cylindrical screen to create centrifugal forces. The solids collect on the screen, while the liquids pass through
- Tangential Flow Separators (TFS): these typically include a lime slurry tank; a pre-flocculation tank; a TFS tank; a thickening tank; and associated pumps and flow meters. They achieve very high P removal rates
- Dissolved-Air Flotation (DAF): these dissolve air into effluent held within a pressurised tank. Dropping the pressure causes air bubbles to form. Fine solids attach to these and float to the surface where they are skimmed-off. Heavy solids sink and are discharged through an outlet in the base of the tank. Liquid is released through a separate outlet.

TABLE 1 Summary of performance of a range of solids separation systems

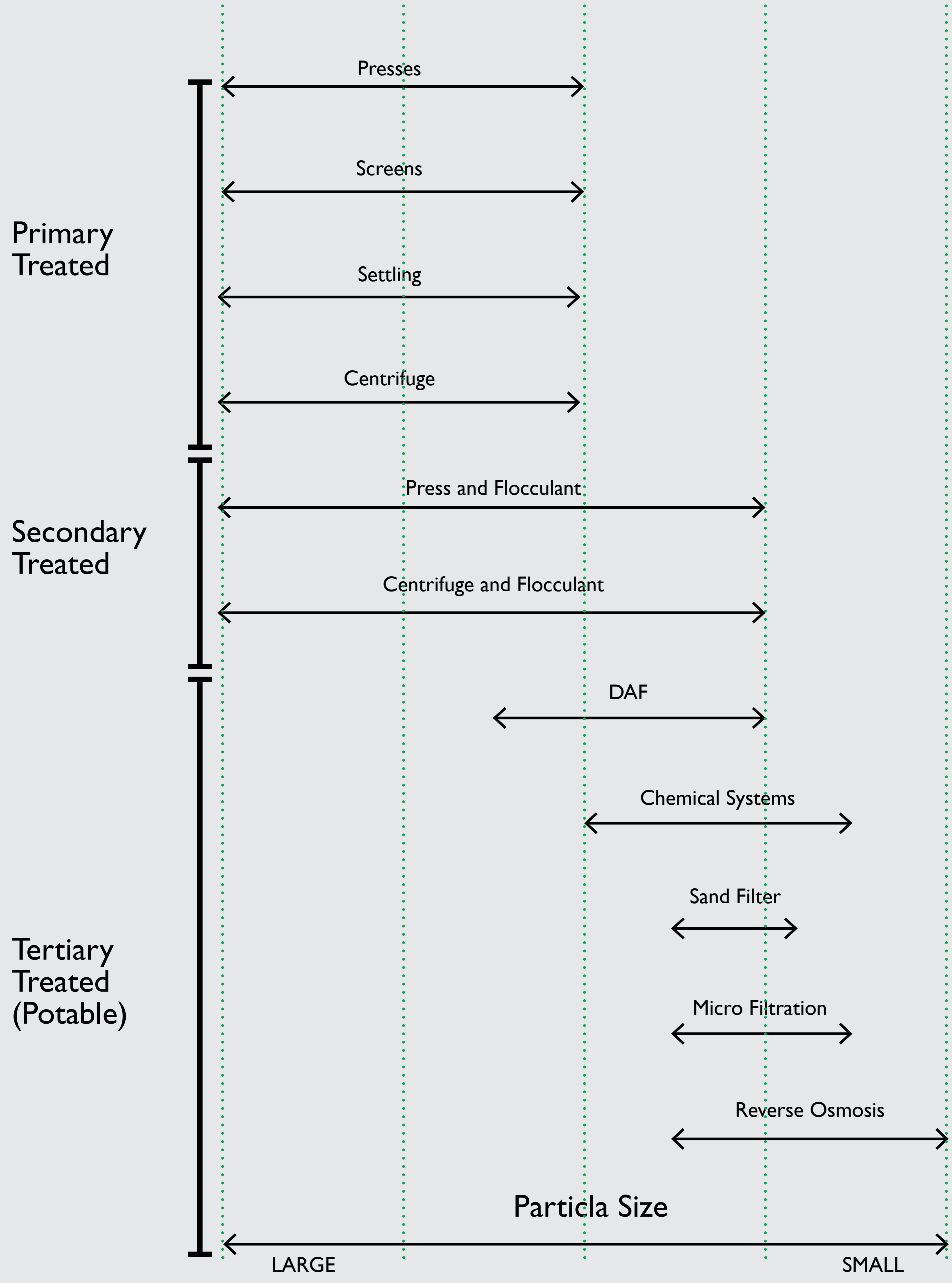
Separation system	Indicative capital cost range	Indicative operating cost range	Solids dryness	Maintenance and supervision	Degree of operator training	Pre-treatment needed	Removal Efficiency (% of total solids (TS))	
							1.2 %TS	3.1% TS
Sedimentation basin	Low-medium	Medium to high	Low	Medium	Low	Nil	50	50
Sedimentation and evaporation ponds	Low	Low	Low	Low	Low	Nil	60	60
Static rundown screen	Medium	Low-medium	Low	Medium	Low	Nil	20	20
Vibrating screen	Medium	Low-medium	Medium	Medium	Low	Nil	10	20
Rotating screen	Medium	Low-medium	Medium	Medium	Low	Nil	10	15
Baleen filter screen	Medium-high	Low-medium to medium	Very low	Low	Low	Nil	30	30
Screw press separators	Medium-high	Low	High	Low	Low	Nil	10	20
Belt presses	Medium-high	Medium	High	High	High	Nil	10	20
Hydrocyclones	Medium	Low	Low	Low	Low	Coarse screen	25	25
Centrifuge/decanters	High	Medium to high	High	Low	Medium	Coarse screen	20	30
Dissolved air flotation	High	Medium to high	Low	Medium-high	Medium-high	Screen + polymer	70	70
Tangential flow Separators	High	High	Low-medium	Medium	Medium	Screw press	50	50

Note: A TS content of 3.1% is quite high for piggery effluent and represents a scenario where low flushing water volumes are used. A TS content of 1.2% is fairly typical for piggery effluent where high flushing water volumes are used. Generally, a larger amount of solids leads to a lower operating cost/ML of effluent treated.

Based on Watts et al. (2002b)

FIGURE 4 **Summary of piggery effluent characteristics and solids removal systems**

Piggery Effluent	Floating	Settled	Suspended	Dissolved
N	1–10%	15–30%	10–20%	50–70%
P	1–10%	50–70%	20–30%	10–20%
VS	1–10%	55–75%	5–15%	10–20%
TS	1–10%	55–75%	5–15%	10–25%



Watts et al. 2002b

6.4 Effluent Treatment Ponds

Earthen-lined anaerobic ponds are the most common effluent treatment ponds used by piggeries. However, concerns about odour and GHG emissions, and opportunities to collect biogas for use as a power source, are driving a move towards heavily-loaded, covered anaerobic ponds from which biogas can be collected. Other types of treatment ponds, evaporation ponds and holding ponds may also be part of the effluent treatment system.

6.4.1 Environmental Protection Principles

To protect groundwater, the walls and floor of all effluent ponds should be lined to achieve a maximum permeability of 0.1 mm per day or approximately 1×10^{-9} m/s. In most cases clay can be used as a liner (see Appendix 1: Pond and Pad Permeability Specifications), although synthetic liners are an alternative (see Section 6.4.7). Effluent pond bases need to be at least 2 m above the highest seasonal water table. In locations with shallow groundwater, excavated effluent ponds may not be an option and above-ground, or turkey's nest ponds may be needed.

To protect surface waters, the overtopping (spill) frequency should not exceed 1 in 10 years. All ponds need a bank to exclude extraneous stormwater runoff that can contribute to more frequent spills. They should also have freeboard of at least 500 mm to provide for wave action. Ideally effluent should be transferred between ponds under gravity flow using a pipe or a weir through a shared wall to avoid reliance on pumps to transfer effluent. Where pipes are used, sewage-class Poly Vinyl Chloride (PVC) or High Density Poly Ethylene (HDPE) pipes at least 150 mm in diameter are recommended.

Ponds need to be designed and managed to ensure acceptable odour releases. In very sensitive locations, pond covering to minimise odours may be an option (see Sections 6.4.2.6 and 6.4.2.7).

6.4.2 Anaerobic Ponds

Most conventional piggeries in Australia use uncovered anaerobic ponds to treat effluent. They are relatively cheap to build, can treat high strength effluent and have some tolerance of variations in the quality and composition of effluent for treatment. Photograph 10 shows anaerobic ponds at a conventional piggery.

Anaerobic ponds provide a convenient and simple method for stabilising organic matter into less reactive compounds and gases. They can reduce the volatile solids content of the effluent by up to 70% using a two-stage process. Firstly the organic matter in effluent is broken down to form Volatile Fatty Acids (VFAs). Secondly these are converted into inoffensive methane) and carbon dioxide. The bacteria that are responsible for the second stage are highly sensitive to pH. The pH of pond effluent should be in the 6.8–8.0 range that suits the target treatment bacteria. If the effluent becomes too acidic, the second stage will be impaired, releasing odorous VFA's. The odour released from uncovered anaerobic ponds under these circumstances is a significant downside to their use.

Photograph 10 Anaerobic pond at conventional piggery

6.4.2.1 Aims

Anaerobic ponds can be large and lightly loaded or smaller and more heavily loaded. In both cases there are four main aims:

- To contain and store effluent
- To keep odour emissions acceptably low
- To allocate enough space for sludge storage between desludging
- To ensure that effluent and sludge from the pond can be removed for reuse as needed.

6.4.2.2 Design Principles

Design principles for anaerobic ponds:

- Pond capacity depends on the organic matter load and the acceptable desludging frequency
- Pond depth is generally 2–5 m
- Depth to groundwater from the excavated base elevation should always exceed 2 m
- Pond shape should assist content mixing and desludging – while narrow, long ponds are more easily desludged (refer to Section 6.4.9 for options), contents mixing may be restricted and solids may accumulate more rapidly near the inlet point. Providing multiple inlet points helps
- Inlet pipes or channels should discharge into the pond beyond the toe of the pond wall, preferably at multiple locations for large ponds; these need to be accessible for ease of unblocking
- The base and walls should be impermeable (see Appendix 1: Pond and Pad Permeability Specifications). Synthetic lining is also an option (see Photograph 11 and Section 6.4.7)

- Pond banks need to allow safe access for desludging and maintenance; bank tops should be 2.5–4 m wide, external batters or ramps for vehicle access and slopes that need mowing should not exceed 3:1 (horizontal to vertical), internal banks should be constructed to maintain their integrity, internal wall slope below water level should not exceed 2:1 (horizontal to vertical). Covered and plastic lined ponds generally have steep internal banks (e.g. 2:1) while flatter internal bank slopes (e.g. 3:1–4:1) that provide for machinery access during construction and maintenance are more common for other ponds. Flatter slopes are safer for driving on but require a larger surface area for a given volume. A slope ratio of: 2:1 = ~27°, 3:1 = ~18° and 4:1 = ~14°
- Provide at least 500 mm freeboard
- The overflow frequency of the pond system should be less than once every 10 years, taking into account the effluent inflow, rainfall and stormwater runoff
- Covering heavily loaded ponds eliminates odour.

Photograph 11 Plastic lined anaerobic pond

6.4.2.3 Management

Anaerobic ponds need careful management to maintain a healthy population of the microorganisms used to degrade the manure. It takes some time for new ponds to develop suitable microbial populations. Partially filling new ponds with effluent from a nearby pond or another piggery with the same health status can establish these microorganisms more quickly. Consistently maintaining ideal conditions within the pond helps to sustain the desirable microbial populations. Regular effluent inflows provide a constant food supply. This is important in ensuring the anaerobic digestion process is completed. Anaerobic digestion is a two-stage process. In the first stage, organic matter is broken down into Volatile Fatty Acids (VFAs). In the second stage, the VFA's are converted to low odour methane. However, the methane-forming microorganisms are highly pH sensitive. Irregularly adding large amounts of organic matter to the pond results in increased VFA's and an associated pH drop that compromises the methane formers.

The result is that more of the VFA's are released, increasing odour levels. Some cleaning products and pharmaceuticals may also inhibit microbial activity. Maintaining a generous liquid volume in the pond helps buffer against these effects. pH should be regularly monitored to confirm it is within the ideal range (6.8–8.0). Electrical Conductivity (EC) should also be monitored. Ponds may need to be diluted with fresh water to keep the salinity at an acceptable level.

The performance of anaerobic treatment ponds can be gauged mainly from their volatile solids reduction rate. The need for desludging should be investigated if the anaerobic pond is removing less than half the volatile solids from the raw effluent (determined by testing the raw effluent and the treated effluent) or the volatile solids concentration of the treated effluent exceeds 1% (Skerman et al. 2008). However, volatile solids removal can fall below these levels for other reasons, for example disruption to the pond bacteria by chemicals or a pH imbalance. Difficulties in obtaining representative samples may also introduce error. Hence these limits should be regarded as a trigger for a more detailed investigation of the situation, possibly by collecting and analysing more samples or by measuring the sludge depth by plunging a 0.3 m wide "T" into various sites with the pond.

A purple colour in large anaerobic ponds pond indicates the presence of a group of bacteria that reduce hydrogen sulphide to elemental sulfur, thereby reducing odour. They are considered an indicator of a well-functioning anaerobic pond. Photograph 12 shows an anaerobic pond with purple effluent.

Photograph 12 Piggery pond with purple sulfur bacteria

6.4.2.4 Large Anaerobic Ponds

Traditionally, Australian piggery anaerobic ponds are large, having been sized according to the Rational Design Standard (RDS) proposed by Barth (1985). In Australia, application of the RDS produces pond volumes ranging from 6.0 m^3/SPU in hot climates to 7.7 m^3/SPU in cool climates. The NEGP tabulate suggested anaerobic pond capacities for different climates, desludging frequencies and pre-treatment options. These are reproduced in Table 2. For example, if the piggery is located in a warm climate, does not have pre-treatment of effluent and the ponds are to be desludged five yearly, 4.9 m^3/SPU of anaerobic pond capacity is needed. For a 10,000 SPU piggery, this is 49,000 m^3 or 49 ML of anaerobic pond volume.

Larger anaerobic ponds:

- Usually function effectively with low to moderate odour emissions although function can deteriorate once sludge begins to encroach on the treatment capacity
- Can take up a significant land area and nuisance odours can be released
- May be expensive to build, line and cover (if this becomes necessary)
- Generally require infrequent desludging (once every 5–10 years)
- Can be difficult to desludge because of their dimensions and depth.

TABLE 2 Suggested large anaerobic pond capacities for different climates, desludging frequencies and pre-treatment options

Climate	Desludging Frequency	Effluent Treatment & Desludging Frequency (m^3/SPU)	
		No pre-treatment	Pre-treatment[a]
Cool[b]	Annually	4.6	3.5
	5 yearly	6.0	4.6
	10 yearly	7.7	5.9
Warm[c]	Annually	3.5	2.7
	5 yearly	4.9	3.8
	10 yearly	6.6	5.1
Hot[d]	Annually	2.9	2.2
	5 yearly	4.3	3.3
	10 yearly	6.0	4.6

SPU = Standard Pig Unit

a Assumes a screen that removes 20% of the total solids (TS) and 25% of the volatile solids (VS) (e.g. a stationary run-down screen).

b Based on a treatment capacity loading rate of 60 g VS/m3/day. Examples of localities with cool climates are Armidale, southern and central Victoria, southern South Australia, and Tasmania.

c Based on a treatment capacity loading rate of 80 g VS/m3/day. Examples of localities with warm climates are most of inland New South Wales, South-East Queensland, South Australia and Southern Western Australia.

d Based on a treatment capacity loading rate of 100 g VS/m3/day. Examples of localities with hot climates are central to northern Queensland, Moree and Goondiwindi.

Find the dimensions of a pond with a required volume and water depth

A worked example for a pond with a volume of 20,000 m^3 (20 ML), a water depth of 5 m, freeboard of 0.5 m and internal banks with a slope ratio of 3:1 (horizontal to vertical) is provided.

To calculate top water level (TWL) length and width:

1. Calculate mid-depth surface area

   mid-depth surface area (m^2) = volume (m^3) / depth (m)
   20,000 m^3 /5 m = 4000 m^2

2. Work out some suitable dimensions for this mid-depth surface area.

   e.g. 100 m X 40 m

3. Calculate the top water level (TWL) length and width:

   TWL length (m) = mid-depth length (m) + (2 X (slope ratio x ½ water depth))
   100 m + (2 X (3 x 2.5 m) = 115 m

   TWL width (m) = mid-depth width (m) + (2 X (slope ratio X ½ water depth))
   40 m + (2 X (3 X 2.5 m) = 55 m

To calculate base and crest dimensions:

4. Calculate the base length and width:

   Base length (m) = mid-depth length (m) - (2 X (slope ratio X ½ water depth))
   100 m - (2 X (3 X 2.5 m) = 85 m

   Base width (m) = mid-depth width (m) - (2 X (slope ratio x ½ water depth))
   40 m - (2 X (3 X 2.5 m) = 25 m

5. Calculate the crest length and width:

   Crest length (m) = TWL length + (2 X (slope ratio X freeboard depth (m))
   115 m + (2 X (3 X 0. 5 m)) = 118

   Crest width (m) = TWL width + (2 X slope ratio X freeboard depth (m))
   55 m + (2 X (3 X 0.5 m) = 58 m

   Figure 5 shows the pond dimensions schematically.

Calculate the capacity of a trapezoidal pond (pond with a rectangular surface area and base) with known dimensions.

A worked example for a pond with top water level (TWL) length of 115 m, width of 55 m, depth of 5 m and internal banks with a slope ratio of 3:1 (horizontal to vertical). Note that the TWL should be at least 0.5 m below crest height to allow sufficient freeboard i.e. in this example, assuming 0.5 m freeboard is provided, the pond depth from base to crest is 5.5 m.

1. Determine base length

   Base length = TWL length – (slope ratio X TWL depth X 2)
   115 m – (3 X 5 m X 2) = 85 m

2. Determine base width

   Base width = TWL width – (slope ratio X TWL depth X 2)
   55 m – (3 X 5 m X 2) = 25 m

3. Calculate the area of the pond base

   Base area = base length X base width
   85 m X 25 m = 2125 m^2

4. Calculate the TWL area

   TWL area = TWL length X TWL width
   115 m X 55 m = 6325 m^2

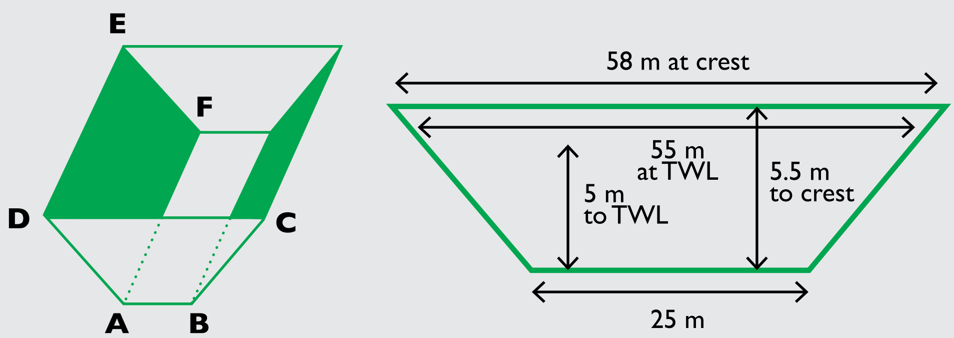
5. Multiply the sum of the TWL and base lengths by the sum of the TWL and base widths

   (115 m + 85 m) X (55 m + 25 m) = 200 m X 80 m = 16,000 m^2

6. Sum the answers from steps 3, 4 and 5, multiply by the depth to TWL and divide the answer by 6 to get the volume in m^3

   ((2125 m^2 + 6325 m^2 + 16,000 m^2)* 5 m) / 6 = 20,375 m^3 or 20 ML

FIGURE 5 Example pond dimensions



Base length (A–F) = 85 m
Crest length (D–E) = 118 m
TWL length = 115 m

Base width (A–B) = 25 m
Crest width (D–C) = 58 m
TWL width = 55 m

6.4.2.5 Small Anaerobic Ponds

Small, more heavily loaded anaerobic ponds can offer the following benefits over RDS-designed anaerobic ponds:

- Lower construction costs
- Easier and cheaper to desludge
- Less odour from uncovered ponds due to reduced surface area and because a crust may form over the pond surface
- Easier and cheaper to cover if this becomes necessary or desirable
- Potential to establish or expand piggeries at sites limited by separation distances.

Recommended design parameters are:

- A baseline volatile solids (VS) loading rate of 750 kg VS/m^3/d for a hot climate which is adjusted for temperature, producing pond volumes of:
  - 0.3319 m^3/SPU in hot climates
  - 0.4148 m^3/SPU in warm climates
  - 0.5531 m^3/SPU in cool climates.
- Very narrow ponds (typically about 3 m) for easy desludging
- Steep but stable internal batters (no steeper than 1 vertical : 2 horizontal)
- Flat end batters to 1 vertical : 4 horizontal if the pond is built with a scraper
- Pond depths of 4–5 m
- Freeboard of 0.5 m
- Low permeability sides and base
- Inlets that provide free effluent outfall into the pond
- Gravity outlet pipes fitted with tees on the upstream end to prevent crust from entering the outlet pipeline, where it can block the pipe or enter the secondary pond (Skerman et al. 2008).

The NEGP suggest minimum anaerobic pond capacities for different climates, desludging frequencies and pre-treatment options. These are reproduced in Table 3. For example, if the piggery is located in a warm climate, 0.41 m^3/SPU of anaerobic pond capacity is needed. For a 10,000 SPU piggery, this is 4100 m^3 or 4.1 ML of anaerobic pond volume.

TABLE 3 Suggested minimum anaerobic pond capacities for different climates

Climate	Suggested Capacity (m^3/SPU)
Cool[a]	0.55
Warm[b]	0.41
Hot[c]	0.33

Based on Skerman et al. (2008)

a The recommended maximum volatile solids (VS) loading rate for treatment capacity in a cool climate is 450 g VS/m^3 pond capacity/day. Examples of localities with cool climates are Armidale, southern and central Victoria, southern South Australia, and Tasmania.

b The recommended maximum volatile solids loading rate for treatment capacity in a warm climate is 600 g VS/m^3 pond capacity/day. Examples of localities with warm climates are most of inland New South Wales, South-East Queensland, South Australia and Southern Western Australia.

c The recommended maximum volatile solids loading rate for treatment capacity in a hot climate is 750 g VS/m^3 pond capacity/day. Examples of localities with hot climates are central to Northern Queensland, Moree and Goondiwindi.

A single, narrow, heavily loaded pond for a large piggery will be very long. Multiple parallel ponds may be preferable. Parallel anaerobic ponds used independently of one another also allows for the temporary decommissioning of a pond for desludging.

Because small, heavily loaded ponds need desludging more frequently, the volatile solids concentration of effluent and treated effluent should be determined on a six monthly basis to confirm that the removal rate is at least 50%. This can be done by analysing raw and treated effluent and using the results to determine the removal rate. Because effluent varies in composition, it is best to collect 20 samples of raw effluent, and 20 samples of treated effluent, that are mixed to produce a composite sample of raw effluent and a composite sample of treated effluent.

VS removal rate (%) = (1 – (treated effluent VS concentration/ raw effluent VS concentration))*100).

The volatile solids concentration of the treated effluent should also be less than 1% (from the laboratory analysis). If not, the ponds probably need desludging.

Photograph 13 shows a small, narrow anaerobic pond.

Photograph 13 Small, narrow anaerobic pond

6.4.2.6 Permeable Pond Covers for Anaerobic Ponds

The most common permeable pond covers are supported straw and synthetic geofabric (e.g. polypropylene or shade cloth) (see Photograph 14). Well maintained permeable covers typically reduce pond odour emissions by at least 50%, and maybe up to 90%. They can be quickly, cheaply and easily installed. However organic cover materials (e.g. straw) can break-down quickly. This affects both odour control and maintenance requirements.

Organic covers are usually supported by an open-weave material that sits on the pond surface (Hudson 2005). A continuous straw thickness of at least 200 mm is recommended. The straw depth needs to be monitored at least six monthly and maintained as needed.

Synthetic geofabric based covers are usually constructed using polypropylene and shade cloth materials. The life of these materials can vary widely. Under Queensland conditions, Hudson (2005) found that non-woven polypropylene shade cloth fabric showed significant deterioration due to UV rays in under 12 months. However, Stenglein et al. (2011) reported that geotextile covers could last up to 10 years in suitable conditions.

Hudson (2005) lists the following requirements for permeable covers to provide an effective on-farm methodology to reduce odour emissions:

- The pond surface must be completely covered
- The cover cannot sink or blow away
- The construction materials must be durable
- The cover must be affordable
- The cover must allow for efficient management and time practices for set-up and maintenance.

Permeable pond covers have not been widely adopted in Australian piggeries. This is partly due to the maintenance requirements, and partly because of increasing interest in covered ponds for biogas collection.

Photograph 14 Semi-permeable pond cover

6.4.2.7 Covered Anaerobic Ponds (CAPs) for Biogas Collection

Methane (CH_4), an important greenhouse gas, is a major product of the anaerobic digestion of piggery effluent. It is also the main constituent of natural gas, a fuel gas. Increasing community interest in greenhouse gas mitigation, and the emergence of opportunities to reduce costs and possibly generate income through capture and use of methane, has led to the development of technologies for its collection. These include Covered Anaerobic Ponds (CAPs) and engineered anaerobic biodigesters. While engineered biodigesters are somewhat more effective than covered anaerobic ponds at converting methane to biogas, they typically have a significantly higher capital cost which can be cost-prohibitive and can be more difficult to operate than covered ponds. By contrast, covered anaerobic ponds can offer a cost-effective, simple and robust option, although sludge management can be an issue. Most of the installations to date in the Australian pig industry have been covered anaerobic ponds, and both engineered systems and covered anaerobic ponds are planned for future projects. Producers can obtain further information and assistance on biogas from the Pork CRC Bioenergy Support Program: http://porkcrc.com.au/wp-content/uploads/2013/11/Bioenergy-Support-Program-Talking-Topic-1.pdf.

A covered anaerobic pond is an earthen pond fitted with an impermeable cover that collects biogas released by digestion of piggery effluent. Covered anaerobic ponds provide a number of possible advantages over uncovered anaerobic ponds, including:

- Reduced greenhouse gas emissions – this can be achieved by capturing and burning the methane emitted by the pond with a flare, boiler or engine generator, which can reduce overall direct emissions substantially
- Reduced odour emissions – by capturing odorous gases emitted by the effluent treatment system and destroying these by burning or chemical reactions as part of preparation of biomethane for use as an energy and/or heat source
- Providing a possible source of electricity and heat for the piggery by capturing and using the methane in an engine generator or boiler
- Potential to expand or build a larger piggery at a site (required separation distances to receptors may be reduced). The gases produced by effluent treatment typically consist of 60–70% methane, with the remainder mostly being carbon dioxide. This gas mixture is typically called biogas. Because of its high methane content, biogas collected using a cover over an anaerobic pond can be burnt using an open or enclosed flare. The flare flame needs to burn at a high enough temperature to destroy undesirable compounds. If all the biogas is flared there will be reduced greenhouse gas and odour emissions, but no heat or power generation benefits.

The simplest way to recover energy from the biogas is to burn it in a boiler to produce heat and hot water. This can be used in underfloor heating within the sheds or other applications requiring heat.

Cogeneration provides Combined Heat and Power (CHP) generation. In CHP systems, biogas is burnt in a reciprocating gas engine to drive an alternator to produce electrical energy. The heat that is emitted by the engine can be recovered, usually in the form of hot water (70–90°C) (Murphy et al. 2012).

The amount of methane/biogas that can be produced by treating piggery effluent in a pond can vary over a typical practical range of 230–350 m^3/tonne of volatile solids entering the pond. Since biogas consists of about 70% methane and 30% carbon-dioxide, the biogas yield is equal to the methane production (m^3) divided by 0.7. The amount of biogas produced also varies seasonally with pond temperature, with summer yields being 30–50% higher than the winter yields (Birchall, 2010). The financial benefits from using energy on-site are typically greater than exports of electricity to a grid. Hence, when sizing biogas capture and use infrastructure target on-site energy use as a priority. Every cubic metre of methane corresponds to about 34 MJ of combustible energy. Combustible energy production from a conventional farrow-to-finish piggery is around 2000–3000 MJ/d for every 100 sows. A conventional gas generator has an energy conversion efficiency of about 30–40% so 100-200 kWh/d of electrical energy is produced for every 100 sows.

Biogas collection is generally viable for farrow-to-finish piggeries with 500 sows or more, although the threshold depends on energy cost and usage. The remainder of the energy would be emitted in waste heat (a portion of which can be recovered for additional heating). As a guide, about 0.1 kW of power can be generated per breeding sow place in a farrow-to-finish piggery, or around 100 kWh/d of electricity for every 1000 SPU of piggery capacity.

Covered anaerobic ponds have been successfully implemented at a number of Australian piggeries. Recommended design parameters include:

- Pre-treatment to remove coarse, indigestible material and sand from the effluent stream. This helps prevent system blockages
- A pond with a Hydraulic Retention Time (HRT) of 40–50 days or more and a design sludge accumulation life of at least one year; a target volatile solids (VS) loading rate of less than 400 g VS/m^3/day; internal batter slopes as steep as construction contractors can practically achieve while also attaining an appropriate level of compaction; as deep as permissible (consider water table clearance) and a length to width ratio of 2:1 or more where possible
- Covers are usually supplied with a thickness that matches the size of the pond and have been 1.0–2.5 mm thick, high quality geo-membrane such as low density polypropylene (LDPE) or high density polypropylene (HDPE). The geo-membrane material should be procured with a guaranteed life of 10–20 years, including under heat stress and for UV resistance
- The cover should be large enough to fit over the pond surface, making allowance for the pond freeboard and a reasonable perimeter for a trench and positioning of biogas collection pipework
- Biogas collection through a ring piping system which sits inside the cover perimeter area and well clear of the pond liquid level to prevent clogging. This pipeline is generally made from perforated PVC or HDPE (such as slotted PVC or HDPE pipe with burs removed and of adequate size for the required gas flow). These transfer lines are connected to external pipework through a bootweld or via the pond bank with an external/internal moisture collection vessel (a knock-out pot)

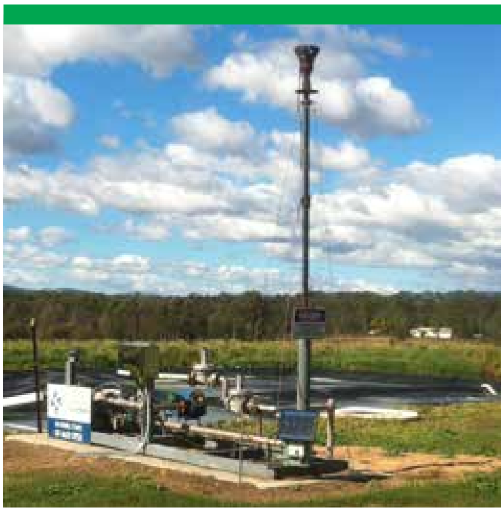
- The edge of the cover is generally trenched to a depth of at least 600 mm with compacted fill to form a gas tight seal which can last in high wind conditions. Water-filled polyethylene pipes are generally placed and fixed onto the cover to weigh it down and to manage rainwater that falls onto it (Heubeck & Craggs 2009; Murphy et al. 2012). The pipe are placed at intervals across the width of the pond to create depressions where the rainwater collects and to direct it to a larger depression in the centre or on one side of the cover, most often to a welded in sump, from which it is pumped away for use as flushing or irrigation water
- A flare is provided to burn left over biogas in the event of seasonal or other excess production, or during a safety or emergency event, and should be sized to be able to clear the biogas under the cover within a reasonable timeframe
- Blowers (exhaust fans) or compressors to help extract the biogas from under the cover and to push/transport the biogas to where it is burnt or used. Monitoring to ensure a vacuum hasn't formed under the cover is recommended. This can be done by daily monitoring of the level of visible bloating of the cover which is indicative of a slight positive pressure (most often less than 50Pascals, even when highly bloated), or with oxygen or pressure sensors (although these are not always reliable)
- Incorporation of sludge extraction ports. If ponds are built as turkey's nests (which store water above ground level), pipes can be inserted at an angle through the wall. The suction line of a vacuum tanker or pump can be fed down the pipes for sludge removal
- Suitable safety management because biogas contains highly toxic hydrogen sulphide which is also corrosive and shortens the life of boilers and generators. The biogas is usually treated in some way to reduce the amount of hydrogen sulphide and in this way lengthen the life of equipment (Davidson et al. 2013).

Photograph 15 shows the process of covering a pond, with Photograph 16 showing the finished covered anaerobic pond. All systems capturing methane must have a flare, regardless of whether other equipment is installed to use the gas (Photograph 17). Flaring the methane converts it to carbon dioxide, reducing greenhouse gas emissions. The methane can also be collected and used to fuel boilers and engines for electrical generation (Photograph 18).

If the piggery is to partake in the Emissions Reduction Fund (ERF) to produce carbon credits for sell-on as a source of additional income, the biogas systems and their operation and monitoring must comply with the most appropriate ERF Methodology Determination: www.comlaw.gov.au/Details/F2013L00124; or www.comlaw.gov.au/Details/F2012L01501; or www.comlaw.gov.au/Details/F2013L00856. Contact with a certified auditor of the ERF early on in the planning and implementation stage is recommended to ensure that the biogas facilities will meet the requirements and the correct monitoring data will be collected for the adopted Methodology Determination.

Photograph 15 Covering a piggery effluent treatment pond

Photograph 16 Covered anaerobic pond with weight pipes installed on cover



Photograph 17 Flare for destruction of methane

Photograph 18 Generator

6.4.3 Facultative Ponds

Facultative ponds combine the features of both anaerobic and aerobic lagoons: the surface layer functions aerobically while the bottom works anaerobically. These ponds are relatively lightly loaded and quite shallow (typically up to 2.5–3m deep). They usually provide further treatment after anaerobic treatment of effluent reduces the volatile solids concentration. Aerators can be used to add oxygen to the surface (Photograph 19) although these are expensive to run.

Photograph 19 Aerator on surface of pond

6.4.4 Aerobic Ponds

Aerobic ponds are commonly used in sewage treatment. These are very lightly loaded and shallow (1–1.5 m deep) to allow for light penetration and oxygen transfer. Even after anaerobic and facultative pond treatment, piggery effluent is likely to be too strong to maintain an aerobic environment throughout the pond. Even mechanically aerated "aerobic" ponds are likely to be facultative due to the loading rate.

6.4.5 Evaporation Basins

Evaporation basins can provide for effluent disposal after pond treatment in dry regions where evaporation rates greatly exceed rainfall. These can be built as long narrow basins along the contour.

6.4.6 Holding Ponds

Feedlot outdoor piggeries need to be located within a controlled drainage area with stormwater runoff collected in a holding pond. Although these are anaerobic, it is difficult to provide a stable environment within these ponds as large amounts of organic matter enter the pond sporadically during rainfall but not at other times. Hence, these ponds are usually intended to hold the effluent before reuse rather than providing treatment (although some will occur during storage). The main design criteria are that:

- Overtopping should not occur more than once every 10 years. Local rainfall data and runoff coefficients of 0.8 for the pens, roads and laneways, and 0.4 for grassed areas should be used in calculating the inflow volumes
- Pond depth is generally 2–5 m
- Provide at least 0.5 m of freeboard
- Depth to groundwater from the excavated base elevation should always exceed 2 m
- Consider how desludging will occur and build this into the design – narrow, long ponds are more easily desludged (refer to Section 6.4.9 for options)
- Pond banks need to allow safe access for desludging and maintenance; bank tops should be 2.5–4 m wide; external batters or ramps for vehicle access and slopes that need mowing should not exceed 3:1 (horizontal to vertical); internal banks should be constructed to maintain their integrity; internal wall slope below water level should not exceed 2:1 (horizontal to vertical)
- The base and walls should be impermeable (see Appendix 1: Pond and Pad Permeability Specifications). Plastic (PVC or HDPE) lining is also an option (see Photograph 11 and Section 6.4.7).

6.4.7 Synthetic Pond Liners

Synthetic pond liners are usually made from high density polyethylene (HDPE), poly vinyl chloride (PVC) or similar. This must be UV stabilised material. The permeability of the installed liner must not exceed 0.1 mm/day or approximately 1×10^{-9} m/s. Liners should be designed and constructed by appropriately qualified and experienced specialists to ensure the required permeability standard can be met and maintained for an extended period (e.g. 20 years). Additional design considerations also apply when using synthetic liners.

The pond must be designed and constructed to meet the specifications and requirements of the liner manufacturer so that the liner fits the pond. A single layer of synthetic liner should cover the floor and internal pond walls. Any welded joints or seals must be watertight. The liner should have a uniform thickness over its whole area. Ideally, it should have a smooth finish on both sides, with no embossing. It should be free from pinholes, blisters and contaminants.

It is important to exclude livestock from effluent ponds with synthetic liners as they can quickly damage the liner. Great care must also be taken when desludging synthetically lined ponds to prevent damage to the liner.

6.4.8 Effluent Pond Management

The pond system needs to be managed to ensure the environmental protection principles are met. Management information specific to anaerobic ponds is provided in Section 6.4.2.3. Since effluent ponds pose a drowning risk they should also be fenced with prominent warning signs displayed.

The outer banks of effluent ponds should be grassed to prevent weed infestation, cracking and erosion. Keeping the grass short allows for regular inspections to detect bank deterioration. Trees, shrubs and woody weeds can damage the bank and must not be allowed to establish. Vegetation should not be allowed to grow into the pond as it can impede access and clog pipes and weirs.

Clay liners that dry out may crack; ideally fill ponds as soon as practical after construction and retain water in the pond. Pond covers and liners need regular inspection to ensure they are in good condition. Ponds with covers or synthetic liners, in particular, should also be fenced to protect them from livestock trampling (see Section 6.4.7). Care needs to be taken during desludging to maintain liner and cover integrity. Options for desludging ponds are detailed in Section 6.4.9.

Effluent reuse should be managed to use the organic matter and nutrients to grow crops and avoid effluent overtopping (spills).

Contingency plans are needed to manage emergency situations like pump breakdowns, power shortages, pipeline blockages, entry of foreign substances to the ponds and overflows.

6.4.9 Pond Sludge

Sludge accumulates continuously in effluent treatment and holding ponds, mainly in the primary pond. It accumulates more quickly in systems that frequently remove sludge (e.g. systems in which vacuum tankers are used to remove sludge with effluent for irrigation) than in those that leave the sludge undisturbed. This could be because treatment microorganisms are removed with the sludge, affecting digestion of the incoming effluent. Hamilton (2010) suggests a sludge accumulation rate of 0.0012 m^3/kg total solids for ponds that leave sludge to accumulate for at least 10 years without disturbance. The sludge accumulation rate also escalates when sludge exceeds about 30% of the pond volume. Birchall (2010) estimated a sludge accumulation rate of 0.00094 m^3/kg total solids for a covered anaerobic pond located in Northern Victoria

Regardless of the sludge accumulation rate, maintaining sufficient treatment volume in the pond is very important. The need for desludging should be investigated if volatile solids reduction in the anaerobic pond falls below 50% or the volatile solids concentration of the treated effluent exceeds 1%. The volatile solids reduction rate can be determined from laboratory analysis results for raw and treated effluent. Because effluent varies in composition, collect 20 samples of raw effluent and 20 samples of treated effluent. Mix all the raw effluent samples together and all the treated effluent samples together to produce composite samples of raw effluent and treated effluent.

VS removal rate (%) = (1 – (treated effluent VS concentration / raw effluent VS concentration))*100).

To prevent sample deterioration, the samples need to be kept cool and transported promptly to the laboratory.

The options for pond desludging depend on the physical properties of the sludge, pond design and accessibility and the land area available for sludge management. Effluent containing up to 5% solids can usually be pumped. Slurries with a total solids concentration of 5–15% can be extracted with positive displacement pumps. Sludge with a total solids content exceeding 15% is too thick to pump and must be removed using bulk mechanical methods. The total solids content of sludge sampled from a number of Australian piggeries ranged from 3.2% to 16.4%. The bulk density of the samples was similar to water (range: 1004 to 1103 kg/m^3) (O'Keefe et al. 2013).

When desludging ponds, there are three techniques depending on the pond design, sludge physical properties and the desludging frequency. These are:

- Desludging dewatered ponds (after effluent removal);
- Desludging an uncovered pond containing effluent; and
- Desludging a covered pond.

For ponds containing very old or thick sludge, it is often cheapest to dewater the pond before removing the sludge using excavators or other earthmoving equipment (see Photograph 20). However, it is usually preferable to remove sludge without dewatering so that use of the pond can continue. There are three basic methods for removing sludge from an operating, uncovered pond. These are:

- Pumping using a positive displacement pump or vacuum tanker. The sludge in the bottom of the pond may be agitated to enhance solids removal
- Dredging – this uses a pump that moves across the surface of the pond, allowing access to all parts of the pond
- Mechanical removal – a long reach excavator, or similar equipment, is used to remove the sludge without pumping.

A rotary positive displacement pump is a cost-effective method of removing sludge as the pump does not need to be continually manned. However, the suction hose requires frequent repositioning. Pipe blockages and pumping of clear effluent (rather than sludge) can be a problem. Photograph 21 shows sludge removal with a mono-pump.

Vacuum tankers are labour intensive, particularly if the sludge has to be moved any distance for dewatering or spreading. They can be a good option for small piggeries that spread sludge directly, or where dewatering basins are located close to the pond that is being desludged. Photograph 22 shows sludge removal using a vacuum tanker.

A suction dredging system is capable of desludging large ponds without being continually manned. However, sludge removal may be inefficient in ponds with variable sludge depths. Pump blockages are also a risk. Photograph 23 shows a pond dredging system in operation.

Photograph 20 Sludge removal with a long-reach excavator

Photograph 21 Sludge removal with a Mono-Pump

Photograph 22 Sludge removal using a vacuum tanker and agitation (Source: Alan Skerman, DAFF)

Photograph 23 Pond dredge in operation (www.dredgingsystems.com.au)

Material removed with an excavator has a higher total solids content than pumped material. However, this is a labour and time intensive system. There is also a significant risk of damage to the pond liner (if fitted).

Sludge removal from covered anaerobic pond presents specific difficulties as the cover cannot be removed during the operational phase. There are three main options for sludge removal from covered anaerobic ponds:

- In-situ desludging – the solids settle to the base of the pond and are removed by pumping through pre-installed pipelines
- Suspension removal – solids are kept in suspension using agitators within the pond. The solids are removed as part of the outflow from the pond
- Life-time accumulation – solids are allowed to settle and are not removed until the operational life of the pond cover ends and the cover is removed. To allow for this, a general sludge-accumulation volume needs to be built into the pond design.

Modern primary pond designs often feature narrow ponds (less than 35 m width) that are more easily desludged. In some cases these are built as turkey's nests with pipes inserted at an angle through the part of the wall that is above ground level. Typically several pipes are arranged at intervals along the length of the pond to provide access to the entire pond base. Sludge can be removed by feeding the suction line of a vacuum tanker or pump down the pipes. This desludging method minimises disruption to pond function and the risk of damage to liners and covers. For covered ponds, it appears that frequent removal of recently settled sludge (<3% total solids) would be preferable to infrequent removal of densely settled sludge. However, more research is needed to optimise the desludging frequency, the arrangement of pipes over the floor of the pond and pump selection. Photograph 24 and Photograph 25 show installed sludge removal pipes.

Dilute sludge slurries can sometimes be pumped, or transported in a vacuum tanker, directly to a reuse area for spreading. However, in most cases sludge needs to be dewatered for ease of management.

Photograph 24 Sludge extraction pipelines (deflated pond cover)

Photograph 25 Pump suction pipe inserted into in-situ desludging pipe

Sludge drying is particularly important if the reuse site is some distance from the source. Methods for dewatering sludge include:

- Long-term storage
- Short-term drying bays
- Sedimentation and Evaporation Pond Systems (SEPS)
- Geotextile tubes.

The most common method of sludge drying is simply to place the sludge in a large, bunded area. To reduce the footprint, the sludge depth can be significant (>2 m). The major downside of this method is that it takes a long time (many months to years) to dry the sludge. Typically the sludge crusts over, limiting evaporation. However, if storage time is not an issue this is a viable sludge dewatering method.

Sludge can be dewatered more quickly using purpose-built, shallow evaporation bays (see Photograph 26). Clay lined evaporation bays are cheap to build and offer good groundwater protection. The dewatering rate can be improved by laying down a gravel base, adding slotted pipes across the bay, then covering these with fine graded sand. However, this adds cost and there is a risk of pipe damage by machinery when the sludge is removed. Another option is to use geofabric walls and a sand layer over a clay base. This allows for drainage through the walls and the base, further enhancing drying. The clay base underneath all of these bays needs to meet the same permeability standard as effluent ponds (see Appendix 1: Pond and Pad Permeability Specifications). Bays about 0.6–0.7 m deep can be filled to a depth of 0.3–0.4 m and provide 0.3 m of wet weather storage. They need to overtop at a frequency of less than once every ten years (or spills are captured by ponds designed to meet this criterion). The length and width of the bays will depend on available space and the amount of sludge. Sludge can be removed from the bays for storage or composting in windrows when the moisture content drops to around 50% when handling is easier. The moisture content of the sludge can be tested by collecting a composite sample (at least 10 sub-samples, thoroughly mixed) and having them analysed. To prevent sample deterioration, the samples need to be kept cool and transported promptly to the laboratory. Alternatively, trying to form a sample of sludge into a stable pile about 1.5 m high will identify whether it is dry enough for windrow composting or storage.

Sedimentation and Evaporation Pond Systems (SEPS) were originally developed to avoid the difficult problem of removing sludge from large, deep conventional ponds. They typically consist of two or three parallel earthen channels that are narrow, shallow and trafficable. The shallow depth allows for rapid drying of solids. Although SEPS were developed for effluent treatment, they are also suited to sludge dewatering. Unlike short-term drying bays that are usually batch-loaded, SEPS are larger and can be continually loaded. More information on SEPS is provided in Section 6.3.3.

Photograph 26 Sludge drying bay

Geotextile tubes are widely used with sewage sludge and have been tested with livestock manures and pond sludge. The tubes mainly use drainage, and a little evaporation, to efficiently dewater the sludge. They could be an option in sites that do not lend themselves to construction of drying bays or SEPS because of land area or topographical constraints. However, they are generally a more expensive option, particularly if coagulants or flocculants are used to enhance the process.

Pond desludging and drying is often a slow and challenging process. Before desludging consider:

- Proximity to neighbours, seasonal conditions and prevailing winds - avoid desludging during times of the year when prevailing winds are towards sensitive receptors or when receptors are likely to be around (e.g. Christmas/New Year, school holidays)
- Sludge removal options taking into account the pond dimensions and the physical properties of the sludge for removal
- The amount of sludge for removal, management and reuse
- Whether the pond will be decommissioned for desludging – if so, consider decanting most of the liquid before desludging commences to avoid paying for dewatering and extra transfer costs
- How effluent will be managed if a pond needs to be decommissioned during desludging
- Sludge dewatering method, including where and how long the extracted sludge will be stored
- Where the sludge will be stored (if it is not spread immediately)
- How the sludge will be reused.

6.5 Odour and Vermin Control

The piggery effluent treatment system can be a significant source of odour. Under stable conditions odour levels are relatively low. However, when there is disruption to the system, for instance because of the entry of chemicals or an unusually heavy influx of organic matter, the microorganisms responsible for effluent digestion may be disrupted. This may result in incomplete digestion of effluent with resultant release of odorous gases. In most cases the pond system will recover within a week or so. Nevertheless it is very important to carefully manage the system to prevent nuisance odour generation. In the event of an ongoing problem, modifications to the system, which could include pond covering, should be considered.

Flies, mosquitoes and rodents are attracted to the wet manure and vegetation found in or near effluent treatment systems. Minimise habitats for these pests by keeping the area around the solids separator clean, regularly moving separated solids to the stockpiling or composting area, and regularly mowing the grass around the entire system. Vegetation should not be allowed to grow into the settling systems or ponds. Strategic baiting can be used in conjunction with the measures described above.

7 Management of Solid Manures

7.1 Introduction

The solid by-product streams of piggeries can include:

- Separated solids
- Pond sludge
- Spent bedding
- Mortalities.

The moisture content and form of these by-products varies (see Section 7.2) and this affects their management. Some are suitable for composting or stockpiling directly. Wet solids require dewatering or the addition of dry material before they can be composted or stockpiled. In some cases, pond sludge is spread directly after removal from the pond using a vacuum tanker. Preferred options for managing mortalities can include composting, burial, rendering and incineration.

Stockpiling and aging involves storing manure in static piles or windrows with little or no active input until it can be spread on land, usually when nutrient inputs are needed for the next cropping cycle. Manure can be stockpiled for up to 12 months or more but more nitrogen losses occur as time goes on.

Composting is a controlled, actively-managed process that uses aerobic bacteria to convert the manure into a humus-like product. Australian Standard AS 4454 (2012) "Composts, Soil Conditioners and Mulches" provides a specific definition for compost, along with processing requirements and details of its physical, chemical and biological properties (Standards Australia Limited 2012). Wet solids may need to be dewatered before being stockpiled and aged or composted.

7.2 Handling Properties of Manure Streams

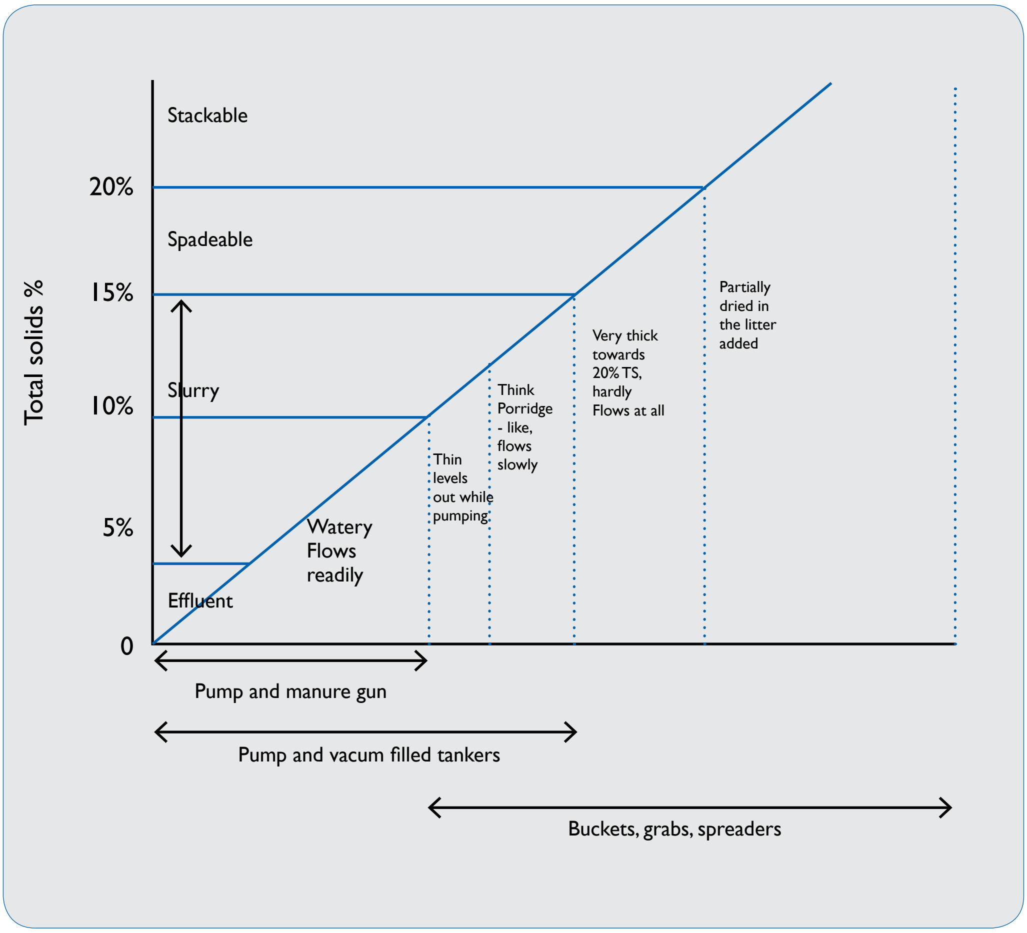
7.2.1 Separated Solids

The total solids proportion, and the particle size distribution, of solids removed by different solids separators varies widely (see Table 1); this affects management of this material.

Figure 6 summarises the handling properties of solids at different moisture contents. Screens remove coarser material that has a low total solids content (~ 5–10% total solids). Screw press solids are also fairly coarse but contain less moisture (~ 20–30% total solids) and are easily managed being stackable with little seepage or slumping. Sedimentation basins and sedimentation and Evaporation Pond Systems (SEPS) yield large amounts of wet solids with a high proportion of fines.

Wet separated solids can be blended with dry bulky materials like sawdust, woodchips or straw to reduce moisture content, increase carbon and improve porosity. Drying them in a shallow basin is an alternative. Details are provided in Section 6.4.9.

FIGURE 6 Handling characteristics of solids at different moisture contents



Watts et al. 2002a

7.2.2 Pond Sludge

The physical properties of pond sludge depend on its age and how it was removed from the pond. In some cases, old sludge may be a high density solid. However, it generally has a high moisture content and, after agitation, may be suspended as a liquid or semi-liquid (~5–15% TS) that can be pumped or suctioned. Unless it will be spread or irrigated directly after removal, it needs to be partly dewatered to improve its handling properties. Sludge drying options are detailed in Section 6.4.9. Once the moisture content of the sludge drops to about 50% it is much easier to handle and can be stockpiled or composted with a carbon source in windrows.

Chemical analysis results for pond sludge are provided in Table 13 in Section 8.5.3.

7.2.3 Spent Bedding

Spent bedding has good handling properties. It is a moist solid (45–60% TS) with a relatively low bulk density that is easy to stack, load and transport. However, the moisture content is usually quite variable within a single batch. It should be mixed to more evenly distribute the moisture content before storage, composting and/or spreading.

Chemical analysis results for spent bedding are provided in Table 14 in Section 8.5.3.

7.3 Quantities of Solid Manures Produced

Knowledge of the quantities of solid manures is needed to determine the size of the solid manure stockpiling or composting area. This depends on the total solids and moisture content of the manure. The manure and waste feed of a standard pig unit (SPU) contributes about 110–125 kg TS/yr to the manure stream, varying between pig classes. Using 115 kg TS/SPU/yr, and data provided in the NEGP, the quantity of separated solids, pond sludge, spent bedding and mortalities has been estimated. These data, which are reproduced in the following sections, can be used as a guide to the quantities of solid manures produced.

7.3.1 Separated Solids

Table 4 provides approximations of the mass and volume of solids removed by different solids separators per standard pig unit. These volumes assume that screened solids are dewatered to a moisture content of 75% before handling.

The data in Table 4 can be multiplied by the number of SPU in a piggery to estimate the mass of solids for a particular unit. For example, a 500 sow farrow-to-finish piggery with pigs to 22 weeks would hold around 5,000 SPU. If a screen is used to pre-treat the effluent, there would be about 230 t/yr or 230 m^3 of screenings to manage. These would dry out and decompose over time, so considerably less than 230 m^3/yr would leave the system.

TABLE 4 Indicative solids removal by different separators

Solids Separator	Assumptions	TS (kg/SPU/yr)	Wet mass (kg/SPU/yr)	Volume (m^3/yr)
Screen	removes 10% total solids, moisture content 75%*, bulk density 1 t/m^3	11.5	46	0.046
Screw press	removes 25% total solids, moisture content 75%, bulk density 1 t/m^3	28.8	115	0.12
Sedimentation basin	removes 50% total solids, moisture content 60%*, bulk density 1 t/m^3	57.5	144	0.14
SEPS	removes 60% total solids, moisture content 60%*, bulk density 1 t/m^3	69.0	173	0.17

* solids are partly dried in basin/SEPS before transfer to solid manure stockpiling or composting site.

7.3.2 Pond Sludge

Sludge accumulates in ponds at a rate of around 0.17 m^3/SPU/yr (based on 0.0015 m3/kg total solids added and total solids production of 115 kg total solids/SPU/yr), less if the effluent is pretreated to remove solids. Hence, for a 500 sow farrow-to-finish unit with no effluent pre-treatment, sludge production would be around 860 m^3/yr or 0.9 ML/yr. If the pond were to be fully dewatered before being desludged with an excavator, about 0.9 ML/yr could be removed. However, the volume removed will vary depending on the required moisture content for the method used. For instance, solids would need to be mixed with liquid effluent to produce pumpable sludge (TS of 5–10%). Table 5 shows the yield of sludge with different effluent dilution rates.

TABLE 5 Sludge production rate (m3/SPU/yr) with different dilution rates

Dilution rate (effluent: sludge)	Volume (m^3/SPU/yr)	Volume for 500 sows farrow-to-finish (m^3/yr)
1:1	0.34	1700
2:1	0.51	2550
3:1	1.02	5100
4:1	1.36	6800

Once the sludge dries to a moisture content of around 50% it can be stockpiled and aged or composted. Sludge consists mostly of fine particles, which have a relatively low carbon content and porosity. For successful composting it should be blended with a carbon source. The optimal ratio of sludge to carbon source should be determined based on sludge analysis results (see Section 8.5.3 for more details).

7.3.3 Spent Bedding

Spent bedding contains both manure and the bedding material. The NEGP provide total solids outputs for each class of pig (108 kg/yr for a grower pig/SPU). They also provide data for the composition of clean bedding materials, which are typically around 90% total solids. Assuming average bedding use of 0.75 kg/SPU/d, this adds 246 kg total solids/SPU/yr. Hence, bedding plus manure adds around 355 kg/SPU/yr. After allowing for decomposition losses of 20% in the shed, about 285 kg/SPU/yr would remain. With an average moisture content of 50%, there is 570 kg/SPU/yr or 0.7 m^3/SPU/yr of material to manage (assuming a bulk density of 0.8 t/m^3).

Bedding is mostly used for weaners, growers, finishers and dry sows. Assuming bedding use of 0.75 kg/SPU/d, clean bedding material adds around 246 kg total solids/SPU/yr. From Table 9.1 of the NEGP, the annual manure and waste feed from a grower pig contains about 108 kg of total solids. Hence, the clean bedding and manure of a grower pig add about 354 kg TS/yr to the system (i.e. 246 kg from spent bedding plus 108 kg from manure and waste feedlot). After allowing for decomposition losses of 25% in the shelter, about 265 kg/SPU/yr would remain (i.e. 354 kg X (1-0.25)). With an average moisture content of 50%, there is 530 kg/SPU/yr or 0.76 m^3/SPU/yr of material to manage (assuming a bulk density of 700 kg/m^3)

(i.e. 265 kg / 0.5 = 530 kg; 530 kg /(700 kg/m^3 / 1000) = 0.76 m^3). The approximate spent bedding production for these classes of pigs is:

- Weaners 265 kg/hd/yr or 0.38 m^3/hd/yr
- Growers 530 kg/hd/yr or 0.76 m^3/hd/yr
- Finishers 860 kg/hd/yr or 1.2 m^3/hd/yr
- Dry sows 870 kg/hd/yr or 1.2 m^3/hd/yr.

7.3.4 Mortalities

The number and mass of pig mortalities generally depends on the size and herd composition of the piggery. In 2010–11, the average sow mortality rate was 10.2%, with a range of 2.0% to 19.2%; while the wean-to finish mortality rate was 0.6%, with a range of 0.1% to 1.7% (APL 2011).

Plans need to be made to handle the typical quantity of mortalities, as well as those resulting from a mass mortalities event. This might mean providing additional capacity in the solid manure stockpiling or composting area.

Mortalities are generally composted with either spent bedding or sawdust. As a rule of thumb, about 6 m^3 of sawdust is needed per tonne of carcasses.

Section 7.7.1 provides details on mortalities composting.

7.4 Manure Stockpiling and Composting Areas

An area is needed to store and manage solid manure until it can be removed from the site for spreading (usually in conjunction with cropping cycles) or further processing. Materials kept in this area may be stockpiled or actively composted. In most cases all solid manure and mortalities will be managed in one area and sufficient space needs to be allocated for their effective management. Additional space will be needed to store any carbon sources or amendments that will be co-composted with the manure or mortalities.

7.4.1 Design of Manure Stockpiling and Composting Areas

Always store or compost solids on a bunded, impervious area. A well compacted pad protects stormwater and provides a durable surface for trucks and heavy machinery. Bunding 0.3–0.5 m high diverts clean stormwater away from the manure, protecting surface water quality and preventing manure from becoming too wet. Within the pad, drainage is promoted by providing an even slope of 1–3%, building windrows with sloping sides (triangular cross section – see Photograph 27) and orienting the long axis of manure windrows down the slope. Runoff from within the pad area should be caught in a holding pond or directed to the effluent treatment system. The holding pond or effluent treatment system must be sized to contain this runoff with a design average overtopping (spill) frequency of once every 10 years. It must also have a low permeability base and walls (see Section 6.4.1).

DAFF (2011) provides a specification for constructing earthen pads with a design permeability of 1 X 10^{-9} m/s (see Appendix 1: Pond and Pad Permeability Specifications.

Photograph 27 Sloping sides on windrows promote shedding of water

7.4.2 Sizing of Manure Stockpiling and Composting Areas

The area needed for composting or stockpiling manure depends on a range of factors including:

- Types of by-products to be stored e.g. manure and mortalities
- Amount of each type of by-product to be managed (Section 7.3)
- Whether any other products will be added to the manure e.g. woodchips (Section 7.3)
- Length of time manure and/or mortalities will be stockpiled or composted
- Stockpiling or composting method e.g. storage in piles versus windrows
- Windrow or pile dimensions
- Space provided between windrows or piles which depends on management and handling equipment used
- Whether the area will provide for emergency composting of mortalities in the event of a mass mortalities incident.

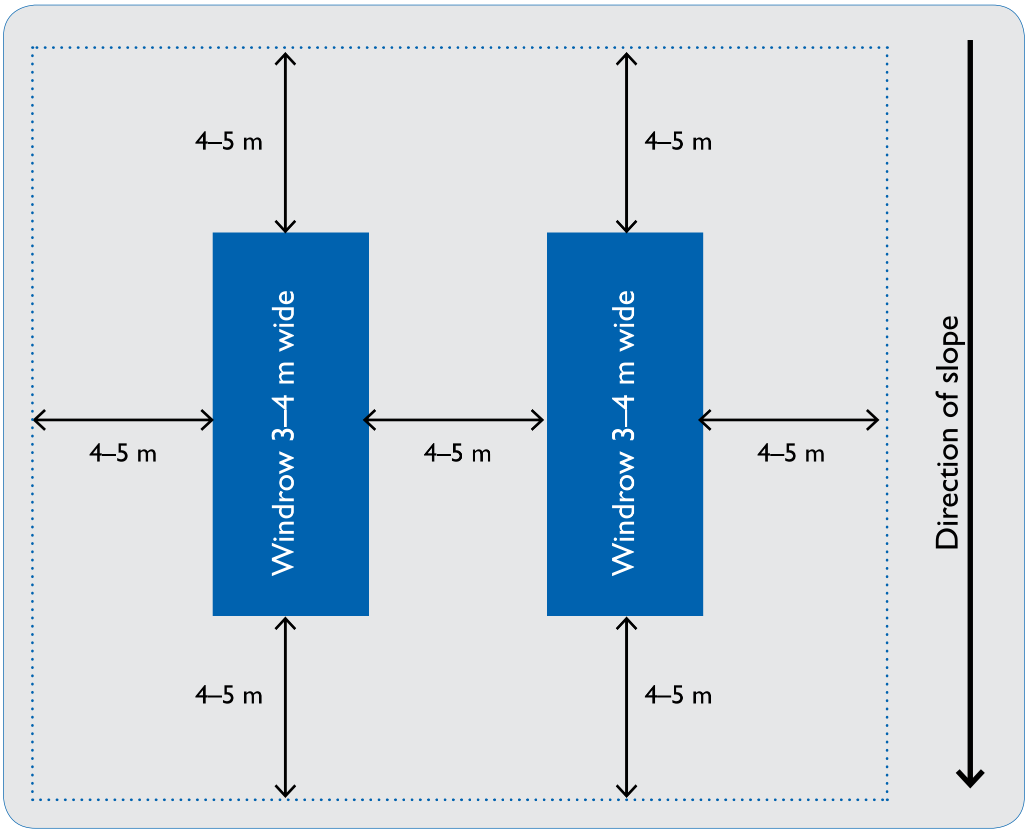
A pile that is 3 m wide at the base and 2 m high stores 3 m^3 of material per metre of length, while a 4 m wide pile that is 2 m high stores 4 m^3 per metre of length. Using data from Section 7.3.3, indicative windrow lengths for composting six months spent bedding from the weaners, growers, finishers and dry sows from a 100 sow herd are provided in Table 6. These values can be multiplied out for larger units. However, the windrow length required will vary depending on herd composition, bedding usage, the moisture content of the spent bedding and other factors.

TABLE 6 **Indicative windrow length needed for storing six months spent bedding from the weaners, growers, finishers and dry sows from a 100 sow unit**

Piggery type	Windrow length	
	3 m wide, 2 m high windrow	4 m wide, 2 m high windrow
Weaners	16 m	12 m
Growers	32 m	24 m
Finishers	68 m	51 m
Dry sows	17 m	13 m

Minimal space is needed between static piles or those that will be turned with a self-propelled, straddle turner. Provide 4–5 m space between windrows if turning with less sophisticated equipment (e.g. tractor-drawn turners, turners that move the pile to one-side, front-end loaders). Figure 7 shows an example layout. When the solids have dried or composted they can be consolidated into larger piles before being spread or taken off-site. These piles should be located within the designated solids storage area.

FIGURE 7 **Space needed for windrows**



7.5 Stockpiling Manure

Stockpiling involves storing manure in piles or windrows that are either unturned or turned occasionally. This reduces the total mass of total solids, volatile nutrients (e.g. N) and often the moisture content too, although this depends on weather conditions. With reductions in total solids and moisture content, the concentration of stable nutrients (e.g. P) increases. Stockpiling may also improve the handling properties of the manure. Stockpiling requires minimal capital and labour inputs compared with composting. However, it is a less controlled process that may produce more odour, is likely to yield a less consistent product, and does not expose all material to the high temperatures needed to kill pathogens and weed seeds.

Wet materials may decompose anaerobically which releases odour and may result in self-combustion. Forming wet solids into low piles (maximum height of 1 m) and turning these promotes drying. The moisture and nutrient content of spent bedding can be very uneven and turning also helps to mix bedding from the dunging area into the drier material. Mixing wet materials with dry, bulky, high carbon material (e.g. straw, sawdust, rice hulls) also dries the solids and introduces oxygen. If wet solids are put in large piles they will decompose anaerobically and release odours. They may also reach high temperatures and the pile can ignite. Manure with an inconsistent moisture content, e.g. spent bedding, should be mixed before stockpiling to avoid these problems.

The height of the pile is important. Piles that are too low will not heat up, a process which assists decomposition, pathogen deactivation and weed seed destruction. Piles that are too high may heat up excessively, particularly if they contain wet manure. Piles up to 2 m in height are recommended. Windrows with a triangular cross-section, a base width of 3–4 m and a height of 1.5–2 m generally work well. The sloping sides shed water. This helps to maintain low odour, aerobic conditions within the pile.

For wetter solids, the manure should be added in layers that are compacted after placement to expel air. Manure fires are an odour and smoke source and can be very difficult to extinguish. Ideally sludge and other wet solids should be stored separately and allowed to dry before being added to piles. Turning this material will promote more rapid drying.

After the manure has been aged for six months it can be transferred to a bigger stockpile to make way for new material.

The amount of aged material produced depends on the amount of material at the start of the process, how fresh the material is and the change in moisture content. Loss of 50–60% of the initial volume could be expected.

7.6 Composting Manure

Composting is the microbiological breakdown of organic matter into compost or humus. Aerobic composting uses organisms that need oxygen to function. It minimises odour emissions from stored manure, emits carbon dioxide rather than methane (lower net GHG emissions) and produces heat that can kill pathogens and weed seeds. However, it is more labour and capital intensive than simply stockpiling manure. Composting can be applied to separated solids, pond sludge, spent bedding and mortalities (covered in Section 7.7.1).

AS4454 – Composts, Soil Conditioners and Mulches defines composting as: *The process whereby organic materials are microbiologically transformed under (generally) aerobic conditions to achieve pasteurisation and a specified level of maturity* (Standards Australia Limited 2012).

Composting involves an active stage and a curing stage. In the early part of the active stage, readily digestible sugars and starches are rapidly broken down and the temperature within the pile rises to over 40°C (typically 50–60°C – Photograph 30). The temperature remains elevated for several weeks providing there is sufficient nitrogen, carbon, moisture and air. Often watering will be necessary to optimise the process. Next, the more resistant materials like lignin are broken down. At the same time pathogens and weed seeds may be destroyed. Finally the decomposed material is converted into humus. Once the temperature within the pile drops, the compost can be cured for several weeks. Curing is important since immature compost may still have high organic acid levels, a high carbon to nitrogen (C: N) ratio and other properties that may be detrimental to crops.

7.6.1 Benefits of Composting

Benefits of composting manure include:

- Reduced bulk and moisture content in the product
- More friable and consistent material which is more easily handled and spread
- Possibility of value-adding on or off farm
- Reduced viable weed seeds and pathogens
- Nutrients stabilised into slow-release form
- Reduction in temporary nutrient drawdown that can occur when fresh manure is spread on soil (nutrient drawdown occurs when soil micro-organisms take nutrients (particularly nitrogen) from the soil to use in breaking down the fresh manure)
- Reduced nitrogen losses on spreading (although nitrogen is lost during composting)
- Increased phosphorus concentration
- Low odour method of managing manure
- Emission of carbon dioxide rather than methane
- More predictable nutrients for application to farming land or for further processing.

7.6.2 Windrow Composting

Manure is most commonly composted in windrows. Material composted in long, low windrows dries more quickly, is easily turned and tends to break down aerobically (low odour). Windrows with a triangular cross-section, sloping sides that shed water, a base width of 3–4 m and a height of 1.5–2 m generally work well (Photograph 27). Lower piles may not heat up enough to pasteurise the manure. Taller piles can get very hot, particularly with wet material, and catch on fire.

The steps in windrow composting are:

- Blend the materials for composting to achieve a suitable carbon to nitrogen (C:N) ratio (15–40:1) and moisture content (material should feel moist but it should be difficult to squeeze water from it). Adding high carbon, bulky materials may not be necessary for spent bedding, but is likely to be beneficial for wet or fine separated solids and pond sludge. Sawdust and wood shavings are ideal carbon sources as they have a C:N of 200-500:1, depending on the tree species. However straw, rice hulls and spent bedding may also be suitable. Consider the surface area and particle size of carbon sources as this influences aeration. Sludge and settled manure will benefit from the introduction of materials with a high surface area to volume ratio and small particle size, such as sawdust and rice hulls, as these allow more air into the piles. Larger sized materials, such as straw, can be shredded or chopped to increase their surface area. Analysing all ingredients to find the C and N content, and designing a recipe to suit, is recommended
- From Table 13, sludge might have a carbon concentration of about 28% and a nitrogen concentration of about 3.41%, making a C:N ratio of 8.2:1 (i.e. 28% / 3.41%). To lift the C:N ratio to a suitable level (i.e. 15–40:1), blend the sludge with sawdust which has a C:N of 350:1. If fourteen parts sludge are blended with one part sawdust, the C:N is 31:1 i.e.

$$((14/15) \times 8.2) + ((1/15) \times 350)$$
$$7.7 + 23.3 = 31:1$$

- Form the materials into windrows 1.5–2 m high and 3–4 m wide at the base. These should have a triangular cross section so that they shed water. Orient the windrows with the long axes perpendicular to the slope. Leave space between and around the ends of windrows to provide access for turning
- Check the moisture content of the material in the newly formed windrow; it should feel moist. If it appears dry and no water is released when a handful is squeezed it is classed as "dry". If water drips from the compost when squeezed, or is leaking from the compost, it is classed as "wet"
- Material that is dry should be watered until it reaches field capacity (moisture content of 40–65%). Some compost turners are also able to apply water (Photograph 28). The windrow can also be watered using a soaker hose or micro-sprinklers positioned along the windrow apex (Photograph 29). Effluent can be used to wet the material for the initial watering; pathogens in the effluent may make it unsuitable for later use depending on how the material is marketed. The windrow must be checked at least hourly during watering to ensure there is no leaching. If the material is too wet, it can be dried by turning every couple of days, or dry co-composting materials incorporated into the pile, until the moisture content is optimal. Large volumes of water can be needed to optimise the composting process. FSA Consulting (2005) investigated the use of piggery effluent as a water source for composting cotton gin waste or cotton gin trash (92%) with piggery sludge (8%). The cotton gin trash had a moisture content of 40.7% while the sludge had a moisture content of 49.8%.

Each time the windrows were turned, effluent was injected into the row to bring the moisture content to field capacity (~60% moisture). A total of 700 litres of effluent was used to produce each tonne of compost. Monitor the pile core temperature and moisture content weekly. The temperature should reach 50–60°C (Photograph 30) within a week or two of the process commencing. A temperature exceeding 60°C poses the risk of spontaneous combustion. Temperature can be monitored using a long probe thermometer inserted deep into the pile at ten separate spots along the length of the windrow. The temperature will be self-regulating providing there is sufficient N, C and moisture for microbial activity. For this reason, temperature is a useful indicator of the composting process. A drop in temperature during the initial phase usually indicates that the material is too dry although insufficient nitrogen can also be an issue. Moisture content can be monitored by applying the squeeze test to handfuls of cooled compost from an arm-length depth at ten sites along the windrow

Photograph 28 Compost turner applying water at turning

Photograph 29 Applying water with micro-sprinklers

7 MANAGEMENT OF SOLID MANURES

Photograph 30 During the active phase the windrow core temperature is typically 50–60°C

- If water is available, material that is too dry should be watered before turning using either a soaker hose or micro-sprinklers along the top of the pile, or a turner with this capability. Care must be taken to avoid over-watering the pile
- Turn the pile only after three successive days of high temperatures (>55°C). The pile should be turned at least three times during the active phase which may take three months or more. Fortnightly turning will minimise labour while creating good quality compost, but the pile can be turned at shorter intervals if it has heated adequately and equipment and labour are available. Thorough turning ensures all material is exposed to the high temperatures that kill pathogens and weed seeds. A strong temperature rise after turning indicates that active composting is still occurring; if the temperature does not rise markedly, and the process has been active for 8–12 weeks, the material is approaching maturity. Photograph 31 shows a compost windrow being turned
- The active phase is considered complete when the pile no longer heats to >55°C after turning
- After completion of the active phase, the compost can be kept in a windrow or formed into a stockpile where it is allowed to cure for at least a month. The end product is friable, humus-like soil conditioner (Photograph 32).

Further information on composting is available on the APL website: www.australianpork.com.au

During the composting process, the pile should be turned only after the core temperature exceeds 55°C for three successive day. The compost should be turned at least three times during the active phase.

Photograph 31 Compost being turned

Photograph 32 Finished compost is a friable, humus-like soil conditioner

Table 7 summarises the recommended composting parameters. Table 8 provides guidance for dealing with common composting problems.

TABLE 7 Recommended composting parameters

Parameter	Acceptable range	Optimum range
Carbon:N ratio	15–40:1	25–30:1
Moisture content (%)	45–65	50–60
Core temperature (°C)	40–65	55–60

TABLE 8 Troubleshooting for common composting problems

Problem	Cause	Solution
Anaerobic odour	excess moisture	turn windrow
	windrow too large	make windrow smaller
	temperature <60°C	turn windrow
	leaf compaction	turn/reduce windrow size; eliminate ponding
	surface ponding	apply odour masking agent (addresses symptom, not cause)
Low windrow temperature	windrow too small	combine windrows
	insufficient moisture	add water while turning
	poor aeration	turn windrow
High windrow temperature	windrow too large	reduce windrow size
	leaf compaction	turn windrow
Surface ponding	depression or ruts	fill depression and/or regrade
	inadequate slope	grade site to recommended slope design
Vectors (rats, mosquitoes)	presence of garbage (food etc)	remove garbage or use rat bait
	presence of stagnant water	eliminate ponding

Biocycle & Composting Equipment Pty Ltd ND

Window composting equipment options include:

- Front-end loaders
- Tractor-drawn PTO-driven units
- Tractor-drawn self-powered units
- Self-propelled straddle turners.

Factors to consider when assessing compost turners include:

- Windrow dimensions – tractor-drawn PTO-driven units; tractor-drawn self-powered and self-propelled straddle turners are better for large windrows and can handle larger amounts of compost. Tractor-drawn models (Photograph 33) are generally limited to piles less than 3 m high, while self-propelled models (Photograph 31) can turn 4 m high windrows. (Note: higher windrows are more likely to reach temperatures that result in fires). The amount of space needed between windrows for different types of turners also needs to be considered.
- Turning rates – 3-point linkage models can generally turn 200–400 m^3/hr, tractor-drawn units 400–800 m^3/hr and self-propelled turners 1200–6500 m^3/hr.
- Power requirements – the required tractor power depends on turner size. For 3-point linkage turners, 35–45 kW will generally be needed while a PTO-driven unit might need 60–100 kW. The tractors will need a creeper gear to enable slow-speed travel or else hydraulic assist on the turner.
- Mode of turning – straddle turners turn the windrow in a single pass so the windrow width must match the drum length. Auger turners lift and move the compost to one side using paddles. They are well suited to composting in small areas as less tractor space is needed beside the windrow.

- Watering – turners that can add water using a trailing hose system (Photograph 28) suit medium to large operations and improves operating efficiency. Some turners can tow a water tanker that applies water during turning. These may suit small operations that don't have other watering infrastructure.
- Amount of manure – Front-end loaders are suitable at small operations; they may already be available on-farm and have a range of uses. However, they are too slow for larger quantities and may not thoroughly mix the pile. 3-point linkage units suit small to medium scale composting. Purpose-built compost turners that mix the compost using an auger, rotary drum with flails or an elevating conveyer are ideal for large scale operations.

It may be possible to differentiate compost by ensuring the process meets the requirements of *AS 4454: 2012 Composts, soil conditioners and mulches*. This is necessary to market material as compost, and may also allow a premium price to be secured, particularly in niche markets. However, costs and benefits need to be carefully calculated. Appendix 4: Manure Valuation Pro-Forma can be used to calculate the nutrient value of the compost.

Photograph 33 Tractor-drawn compost turner

7.6.3 Aerated Static Pile Composting

Aerated static pile composting systems use perforated piping placed under the manure. Pumps or fans push air through the piping and into the pile, allowing for good control over oxygen and moisture levels. Until recently, these systems were generally only used in large, professionally-managed composting facilities. However, suitable technology is now available for smaller-scale operations. Because there is no need to turn the manure, a reduced footprint is required and odour from turning wet manure is avoided.

7.6.4 Quantities of Compost Produced

The rate of compost production depends on the amount of manure at the start of the process and the change in moisture content. Composting generally reduces the initial volume of material by about 40–50% due to losses of total solids (say 30%)

and moisture which can drop from around 50–60% to 40–50%. For example, 1000 m^3 of manure at the start of the process might contain 400 m^3 of solids and 600 m^3 of water (assuming total solids and water have the same density). Around 120 m^3 of solids would be lost, leaving 280 m^3 of solids. With a final moisture content of 40%, the volume remaining is about 466 m^3.

7.6.5 Properties of Manure Compost

Finished compost is a friable soil conditioner. The level of nutrients present depends on the composition of the raw materials used. Analysis of compost is recommended to find the composition.

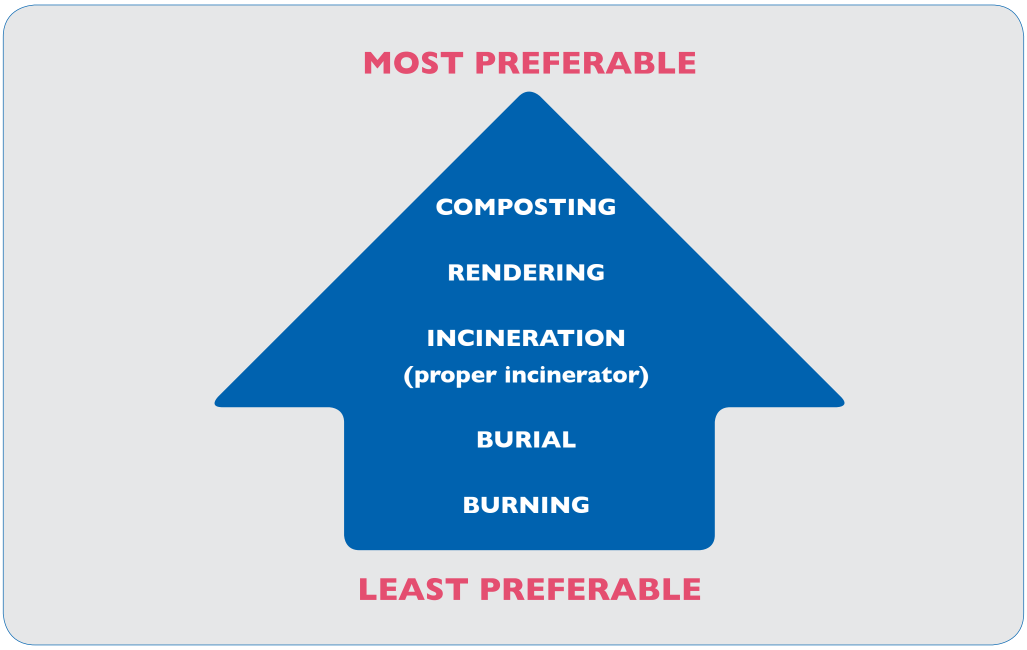
While composting may well destroy weed seeds by heating, the effective loss of viability depends on the temperatures achieved and the length of time they are maintained, the weed variety and all seeds being exposed to the target temperature. While most weed seeds are likely to be killed by composting, the product cannot be guaranteed weed-free.

Similarly, after two to three months of composting, most pathogens should have been substantially reduced in numbers, but some pathogens may still be present in the finished compost.

7.7 Managing Mortalities

Options for managing mortalities are summarised in Figure 8.

FIGURE 8 Mortalities management hierarchy



Mortalities should never be dumped in paddocks as this attracts vermin, is an odour source and poses a biosecurity risk. The various mortalities management options, along with mass disposal, are discussed below with most detail provided for composting.

Regardless of the management method used, mortalities should be promptly removed from the pig accommodation to reduce the risk of disease transfer. Ideally mortalities should be lifted and carried rather than being dragged so that body fluids are not released.

7.7.1 Composting

Composting has been widely adopted as a mortalities disposal method because it:

- Is suitable at all sites but particularly those with highly permeable soils, shallow groundwater or sensitive receptors where burial or burning is environmentally unacceptable
- Is perceived as an improved option environmentally
- Produces a soil conditioner/fertiliser that can be spread on cropping land
- Generates little odour
- Effectively kills most pathogens.

Mortalities composting can be undertaken using bays, bunkers or windrows set-up within a bunded area with an impermeable base. Often this will be part of the manure stockpiling or composting area since similar design and construction standards apply (see Section 7.4.1 and Appendix 1: Pond & Pad Permeability Specifications).

In conventional composting processes, raw materials are mixed to provide a consistent mixture with a C:N ratio of 15–40:1, a moisture content of 45–65% and good porosity that is then regularly turned. However, mortalities composting is different because pig bodies have a large mass, a high moisture content, a low C:N ratio and almost no porosity. Consequently, in the initial stage, the decomposition process close to the bodies is anaerobic. The fluids and gases released then move to an aerobic zone.

Like any composting process, mortalities composting requires adequate:

- Carbon
- Nitrogen
- Oxygen
- Moisture
- Management.

Cover material serves several purposes – it provides a good source of carbon to balance the high nitrogen content of the carcasses; it introduces the oxygen needed by the aerobic microorganisms; and it covers the mortalities which reduces odour releases that cause nuisance and attract vermin. Sawdust or wood shavings are an excellent carbon source (C:N ratio of 200–500:1 depending on the tree species); straw, rice hulls and similar agricultural materials are also suitable. Sawdust has lower porosity than straw or wood shavings; blending sawdust in a 2:1 ratio with straw or wood shavings is recommended to ensure there is adequate oxygen. However, many deep litter and outdoor rotational piggeries use spent bedding as a cover material. There is sometimes sufficient carbon remaining in the compost for it to be useful as a carbon source when the next batch of composting commences. Blending of the compost with fresh bulking material (50:50 mix) is recommended to ensure there is enough carbon to compost additional carcasses. About 6 m^3 of sawdust is needed per tonne of carcasses, or about 0.25 m^3 per sow per year for a farrow-finish unit.

Pig carcasses contain enough nitrogen to supply the composting process. However, because this nitrogen is not evenly mixed through the cover material, the material around the carcass readily composts while the material further away does not. This problem can be overcome with turning after the initial phase.

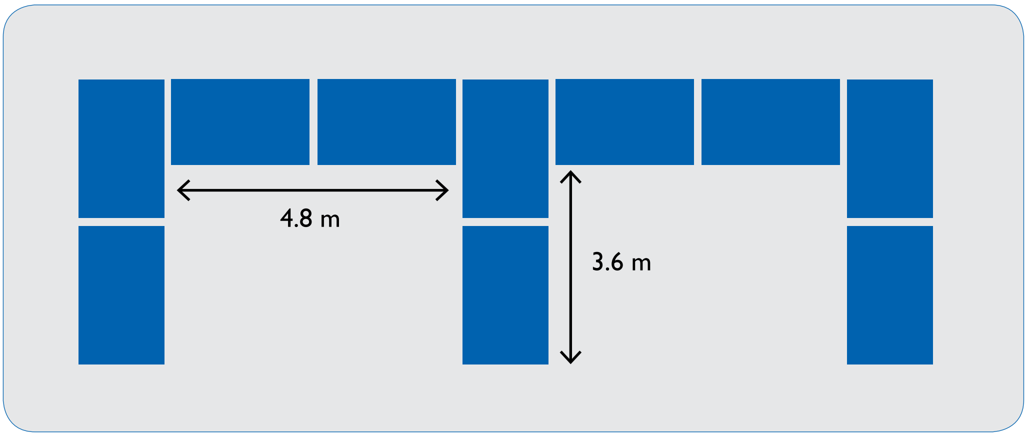
The water in the decaying carcasses, which initially contain about 90% water, generally supplies enough moisture for composting. Wetting the carcasses as they are added to the pile (using one part water or effluent to three parts carcasses by volume) may accelerate the process by generating more microbial activity and heat. Too much water (>60%) restricts air movement and results in odour. Excess moisture is not likely to be a problem provided the piles effectively shed rainfall.

In Australia, pig mortalities are usually composted in bays or bunkers (like silage bunkers), although they can be composted in windrows.

For bay composting, the bays are typically formed from large, square hay bales that are placed end-to-end to form a three-sided enclosure. "Square" bales are typically 4' x 3' X 8' (1.2 X 0.9 X 2.4 m) or 4' x 4' X 8' (1.2 X 1.2 X 2.4 m) in dimensions. At least two bays are needed – one for filling and active composting, one for curing. (Curing allows partly composted materials to complete the process at lower temperatures).

The number of bays needed depends on the mass of mortalities produced per composting cycle. At least three months of composting time (from the placement of the last carcass) and three months of compost curing time is recommended. Some 2–2.5 m^2 of bay area or 4 m^3 of volume is needed for each tonne of mortalities produced annually. Two sets of bays made from 20 large bales (i.e. walls stacked two to three high) provide 17.3 m^2 of floor area per bay (see Figure 9). The bin height is 1.8–2.4 m depending on bale size. These bays should be sufficient for a piggery losing about 7–9 t/yr of pigs.

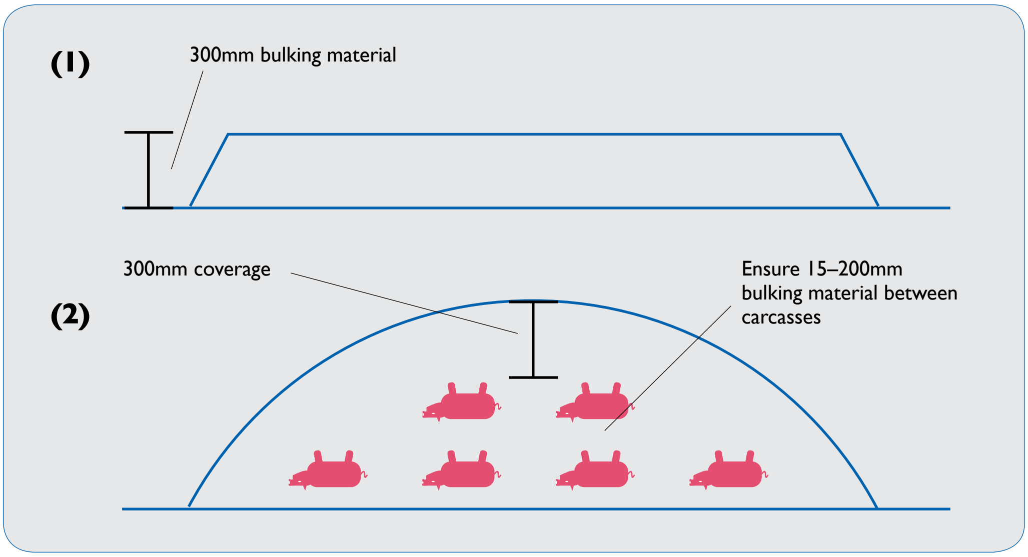
FIGURE 9 Plan view configuration of bays for mortality composting



For windrow composting, provide 0.7 m of windrow length per tonne of mortalities produced annually for windrows with a base width of 3 m and a height of 2 m, or 0.5 m of windrow length for windrows with a base width of 4 m and a height of 2 m.

To start the pile, set-down a 300 mm layer of clean, high carbon material on an impermeable base. This will provide carbon close to the underside of the carcasses and absorb leachate. Place each body on this layer. Opening the thoracic cavity of larger carcasses will release gases that accumulate in the abdomen during decomposition, reducing the likelihood of exposure of bodies due to bloat. Completely surround with a good layer of cover material to ensure no part is exposed. A second layer of carcasses can be placed over the initial layer. These need to be covered with a least 300 mm of high carbon material. Covering this layer with sawdust will assist in shedding rainfall. Once the pile is set up correctly (see Figure 10), the process can be monitored by checking the temperature of the pile.

FIGURE 10 Carcass compost pile construction – base layer (1) and pile with mortalities (2)



The first sign that the composting process is working is the generation of heat within the pile. Core temperature can be measured by inserting a 1 m temperature probe into the pile near the carcasses. The centre of the pile should reach 50–65°C within the first week. Maintaining temperature of >55°C for at least three consecutive days kills or inactivates pathogens. Allow 3–6 months for both the active phase and the curing phase.

In Australia most carcass composting systems use low input management with no turning. However, turning the pile about three months after the last carcasses were added will accelerate the process by improving air flow and promoting mixing. Adding water (if required) when the pile is turned also speeds up the composting process. It is important to cover the pile with high carbon material after turning. The active phase is complete when the temperature within the pile drops. The compost should then be left to cure for a further 3–6 months.

The finished material can be reused in a 50:50 mix with fresh bulking material for future mortality composting, or spread on land. Although the composting process can suppress pathogens, this relies on all material being exposed to high temperatures after turning. Elimination of all pathogens cannot be guaranteed. Consequently, stock should not be allowed to access mortality compost reuse areas for at least three weeks after spreading to minimise the risk of pathogens and protect Australia's BSE-free status. Stock should also be excluded from mortality composting areas.

The nutrient value of the finished compost depends on the type of cover material, the management and whether the material has been recycled for several batches. Typical nutrient analysis is 1.5% N, 0.5% P and 0.3% K when sawdust is used as a bulking agent.

7.7.2 Rendering

Rendering is an excellent mortalities management option as it requires little management, minimises environmental impacts and converts mortalities into meat and bone meal, meat meal and other products. However, it is generally only feasible if the piggery is located very close to a rendering plant. Mortalities need to be stored on a bunded area with an impermeable base while they await collection. This could be a concreted area or a compacted earth pad. Since the rendering plant may refuse mortalities depending on the cause of death, alternatives need to be in place.

7.7.3 Incineration

Correct incineration is rarely feasible on-farm. It requires expensive specialist equipment, similar to that used for disposal of clinical wastes. Usually this involves the use of a complex multi-chamber unit or a pyrolysis system. These typically have a final chamber that operates at 1000°C with a residence time of at least one second to incinerate the odorous gases that may result from destruction of the carcass.

7.7.4 Burial

Burial is often an easy and convenient mortalities disposal option. However, it may pose a groundwater contamination risk particularly in areas with porous soil and shallow groundwater. Many piggeries fail to cover mortalities after placement which releases odour, provides a vermin breeding site and attracts scavenger animals. In some locations, it may only be permissible under the direction of the Chief Veterinary Officer in response to a disease outbreak or mass mortalities incident.

If burial is used, the pits should be sited on clay soils or lined with a clay layer. The base of the pit should be at least 2 m above the highest water table. Splitting the thoracic cavity of larger carcasses after placement in the pit will release gases that accumulate in the body during decomposition, reducing the likelihood of exposure of bodies due to bloat. Immediately after placement, each body should be completely surrounded with at least 30 cm of soil. A further 30 cm of clay should be compacted over filled pits. Mounding over filled pits helps to shed water and provides fill to compensate for subsistence of the bodies as they break down. The mounds should be grassed over. Trees should not be planted over the mounds.

7.7.5 Burning

Burning mortalities in open fires is not a preferred disposal method since it releases smoke, odour, GHG and sometimes biological matter through thermal updrafts. Because of fire bans, burning may not be possible at some times of the year.

For these reasons, mortalities burning is not always permissible, unless this is under the direction of the Chief Veterinary Officer in response to a disease outbreak or mass mortalities incident.

7.7.6 Mass Mortalities Disposal

Effective responses to emergency disease outbreaks require effective planning. This means having a plan in place should the worst situation happen.

The options for mass mortalities disposal depend on the site and cause of death. A suitable area, ideally readily accessible, well separated from sensitive areas (neighbours, watercourses, bores, public land) with low permeability soils and some depth to groundwater, should be allocated for composting and/or burial. The local government and state environment department should be contacted about disposal. State government veterinary officers should be contacted immediately if a disease outbreak is suspected. They will provide advice on the appropriate disposal method in a given situation. Ausvetplan manuals Animal Health Australia (2007) and Animal Health Australia (2011) also provide very useful information for managing mass mortalities disposal.

7.8 Advanced Treatment of Solid Manure

Researchers have investigated the potential to apply advanced treatment technologies to spent bedding and sludge. The most promising technologies appeared to be digestion of effluent using covered lagoons, plug flow digesters and solid state batch digesters. These produce biogas that can be used as a heat and energy source within the piggery.

Spent bedding freshly removed from sheds has a high organic fraction and biological methane potential. Anaerobic digestion using leach bed process with recovery of P from leachate (for fertiliser) may be economically-viable. Stockpiled spent bedding and pond sludge has a relatively low organic fraction and biological methane potential due to the destruction of organics during storage. These materials are unsuited to anaerobic digestion.

7.9 Odour, Dust and Vermin Control

Wet solids, including separated solids and pond sludge, pose the greatest odour risk. Practices that dry these, to allow them to undergo aerobic breakdown, are recommended. Adding dry, porous materials like straw or sawdust or turning frequently will help.

Dust can result from turning of dry manure windrows. Although turning introduces the air needed for composting, it is unlikely to result in heat generation due to lack of moisture. Wetting the material before turning reduces dust creation and will also promote composting.

Flies, mosquitoes and rodents are also attracted to wet manure and vegetated areas near these. Strategic baiting can be used in conjunction with the measures described above.

8 Reusing Manure and Effluent

8.1 Introduction

Piggery effluent, manure and compost can be valuable sources of nutrients and organic matter for improving soil properties and crop or pasture production. Good management is needed to gain the most benefit from these products while protecting the environmental and preventing impacts to neighbours.

While manure and compost may be spread off-site, effluent is less readily transportable and reuse generally occurs on-farm.

8.2 Benefits of Reusing Manure and Effluent

Benefits of responsible manure and effluent reuse can include:

- Increased soil organic matter
- Enhanced soil structure
- Improved rainfall infiltration
- Improved water-holding capacity of soil
- Enhanced soil fertility through increased cation exchange capacity and nutrient retention
- Reduced erosion rates
- Increased plant yields
- Reduced fertiliser costs.

8.3 Selecting a Reuse Area

When selecting a new reuse area, or assessing the suitability of an existing area, consider the following:

- Nutrients are most efficiently removed by growing a high-yielding pasture or crop (Photograph 34) that is harvested and transported from the site. The land should either be able to produce dryland crops reliably or should be irrigated. Grazing removes nutrients at a very slow rate and is not suitable for reuse areas (Photograph 35). Grazing stock need to be withheld from these areas for at least 21 days after effluent irrigation or manure spreading occurs
- Preferably select areas with good agricultural soils with no serious limitations for crop plant growth (Photograph 36). If this is not practical, consider the limitations in the sizing and management of the reuse area
- The reuse area needs to be large enough to sustainably spread the nutrients in the manure and effluent
- Provide buffers between reuse area and watercourses and poorly protected aquifers (e.g. shallow water tables overlain by sandy soil)
- Provide separation distances between reuse areas and neighbours and public use areas. This allows odour, droplets and dust to disperse, reducing the likelihood of nuisance.

Photograph 34 High yielding crops remove large amounts of nutrients

Photograph 35 Grazing removes nutrients at a very slow rate

Photograph 36 Good quality agricultural land is ideal for reuse areas

8.4 Management Practices that Protect the Environment

Good reuse practices are necessary to protect the environment. These include:

- Applying manure and effluent just before sowing, or when plants are actively growing, to maximise nutrient uptake and to minimise nutrient losses by leaching
- Applying the manure, compost or effluent at rates that are sustainable. Consider the nutrient and salt content of the manure and effluent, the land use and expected plant harvest and climatic conditions
- Applying effluent at a rate that does not produce runoff. For surface flow irrigation, use suitable rates and suitable runoff collection methods
- Spreading effluent, manure and compost evenly
- Incorporating spread manure or compost into the soil to a shallow depth (if practical with available machinery)
- Not spreading manure and effluent if the soil is very wet or if heavy rain is expected. This may promote drainage or runoff that poses a pollution risk to groundwater and/or surface waters
- Monitoring soil nutrient levels on a regular basis. This helps in understanding the ongoing suitability of reuse areas and the likelihood of nutrient losses to the environment
- Protecting amenity by using good practices and carefully timing reuse. Choosing to irrigate effluent or spread manure when the prevailing wind direction is away from sensitive location reduces the likelihood of odour impact. Avoid spreading early in the morning or late in the afternoon when inversion layers are forming or under heavy cloud. Dispersion is lower under these conditions so odour and dust levels may be higher for close neighbours. Maintain good communication with neighbours; consult with them before you undertake reuse that could cause odour on their property. Also avoid reuse on weekends or holiday periods when neighbours are likely to be home.

Adopting these practices minimises nutrient exports from reuse areas. When the practices described above are insufficient, secondary control measures can further reduce nutrient losses by reducing soil erosion and filtering nutrients from runoff. These secondary control measures may include:

- Establishing Vegetative Filter Strips (VFS) downhill of the reuse areas
- Installing terminal ponds downhill of the reuse areas
- Installing contour banks on sloping land
- Maintaining continuous ground cover incorporating solid by-products into the soil after spreading (if practical). This reduces the nutrient concentration at the soil surface which may reduce volatilisation of nitrogen, and nutrient losses via erosion or stormwater runoff. However, modern cultivation equipment is often designed for minimal soil disturbance, making it difficult to incorporate manure.

These measures are intended to complement sustainable reuse practices based on mass balance principles and/or monitoring. They are not a substitute for sustainable primary practices.

The NEGP also provide recommended buffer distances from reuse areas to surface waters and separation distances to areas of sensitive land use by reuse category (see Table 9). These can be used in the absence of specific advice from the approved authority. If the environmental risk is low, generally because of the adoption of effective mitigation measures, narrower buffers may provide adequate protection.

TABLE 9 Buffer and separation distances from reuse area

Feature	Category no.		
	1	2	3
Major water supply	800 m	800 m	800 m
Watercourse	100 m	50 m	25 m
Town	1000	750	300
Rural residential area	600	400	150
Rural dwelling	300	200	100
Public road – carrying > 50 vehicles per day	50	25	0
Public road – carrying < 50 vehicles per day	25	15	0
Property boundary	25	20	0

Notes:

1 Distances shall be measured from the perimeter of the area used for handling or reuse of effluent.

2 The fixed separation distances surrounding by-product reuse areas should be used as a guide. Smaller separation distances may be acceptable if a site-specific assessment demonstrates low risk of impacts to sensitive land uses.

3 Traffic volume excludes vehicles associated with the piggery operation.

Categories

Category 1

- Effluent is discharged or projected to a height in excess of 2 metres above ground level
- Separated solids or sludge that remain on the soil surface for more than 24 hours (i.e. are not immediately ploughed in)
- Spent bedding that is spread immediately (i.e. is not stockpiled/composted) and remains on the soil surface for more than 24 hours (i.e. is not immediately ploughed in)
- Flood irrigation systems.

Category 2

- Mechanical spreaders and downward discharge nozzles. The discharged material shall not be projected to a height in excess of 2 metres above ground level
- Spent bedding that has been stockpiled before spreading.

Category 3

- Discharge by injection directly into the soil (to a depth of not greater than 0.4 metres) and at a rate not exceeding either the hydraulic or N, P and K limits determined for the local soil type(s)
- Spent bedding/solids that have been composted
- Application of effluent/spent bedding/solids in combination with immediate incorporation of material into the soil.
- Where more than one category is used the more (or most) stringent category controls will apply.

Ideally buffers should be Vegetative Filter Strips (VFSs) since these can very effectively strip nutrients, provided the soil loss rate is less than 50–70 t/ha/yr. A VFS consists of a strip of dense, runner-developing, non-clump forming grass between a reuse area and a sensitive area. VFSs trap particles and reduce runoff volumes by increasing infiltration. Generally, wider VFSs trap larger amounts of soil eroded from upslope areas. However, for the same soil loss rate, areas with steeper slopes need a wider VFS than areas with gentler slope. Place VFSs as close as possible to the reuse areas to minimise additional runoff through the filter strip. It is also critical to place the VFS before any convergence of runoff. VFSs become ineffective where flow concentrates in depressions before entry into the filter strips. As needed, the area should be levelled to remove depressions, or the VFS developed along the contour (Redding & Phillips 2005). Table 10, taken from the NEGP, recommends a range of VFS widths appropriate for various conditions. These designs are for a maximum slope length above the VFS of 200 m.

TABLE 10 Grass VFS widths (m) for typical soil loss rates and filter gradients

Soil loss (t/ha/yr)	Filter strip slope (%)								
	1	2	3	4	5	6	7	8	9
10	5	5	8	8	9	9	10	10	10
20	6	12	15	15	15	16	16	16	16
30	12	18	21	21	22	22	22	23	23
40	18	24	27	27	28	28	29	29	29
50	25	>30	>30	>30	>30	>30	>30	>30	>30

Adapted from Karssies and Prosser 1999, page 28 cited by Tucker et al (2010).

Terminal ponds can be located below reuse areas to catch the first flush (often 12 mm) of nutrient-rich runoff from a reuse area. Although these ponds may overflow during a significant rainfall event, they do slow the flow rate and allow for settling of suspended soil and organic matter particles. The runoff captured in these needs to be irrigated onto a suitable area when the soil is dry enough.

Contour banks on sloping land reduce the velocity of runoff and hence erosion. They capture and redirect runoff from smaller areas of a paddock, preventing runoff from concentrating into larger streams that erode large volumes of soil. While these may effectively prevent the loss of nutrients attached to soil, they do not prevent the loss of nutrients dissolved in runoff.

Maintaining continuous groundcover over reuse areas promotes infiltration of rainfall and reduces runoff, water velocity and soil movement. This reduces nutrient removal due to soil erosion and also increases nutrient infiltration.

Separating reuse areas from nearby sensitive land uses can help to reduce amenity impacts. The NEGP provide recommended separation distances for different reuse categories. These are reproduced in Table 9.

8.5 Nutrient Budgeting

Nutrient budgeting is the corner-stone of sustainable reuse. Appropriate rates can be determined using a mass balance that considers:

- Nutrient status of soils
- Nutrients (N, P and K) added to the land in manure and/or effluent
- Acceptable nutrient losses (i.e. ammonia-N losses)
- Acceptable soil storage of stable nutrients (e.g. P). This can only be a temporary measure and there needs to be a plan to remove stored nutrients
- Nutrient removals through crop harvest
- Management of salt in effluent to prevent leaf burn and soil degradation.

8.5.1 The Nutrient Mass Balance Equation

The nutrient mass balance equation is:

> Nutrient application rate = nutrient removed by plant harvest + acceptable nutrient losses to the environment + nutrient safely stored in the soil

Approximate N, P and K removal rates for different crops and yield ranges are provided in Table 11.

The nutrient application rate is the product of the nutrient concentration in the manure or effluent and the application rate. As the composition of manure and effluent varies from farm to farm, a representative sample should be collected and analysed annually just before the main irrigation or spreading time. This equation must be determined for N, P and K.

Nutrient removed by plant harvest is the product of crop yield and nutrient content of the harvested material. High yielding fodder crops usually remove the most nutrients. For grain crops, nutrients can be removed through the harvest of grain and straw. Crop yields can vary widely. Historical yield data for the farm or other farms in the district can provide a guide. There may be a need to adjust nutrient application rates following dry seasons.

When manure or effluent is spread or irrigated, gaseous losses of N are generally unavoidable.

As a percentage of N removed by the crop, these are typically:

- Spray/drip irrigation of effluent 20% of N
- Surface flow irrigation of effluent 10% of N
- Spreading of fresh bedding 20% of N
- Spreading of compost 10% of N.

The amount of N released when solids are applied depends on how they have been managed. Higher N losses would be expected from fresh spent bedding (e.g. 20%) while losses from stockpiled or composted material (about 10%) or sludge will be lower. Incorporating spread solids into the topsoil helps to reduce N losses. However, modern cultivation equipment usually minimises soil disturbance, resulting in minimal manure incorporation.

Except for P, soil storage of nutrients is generally small and can be disregarded. Soil P storage capacity depends on soil type (soils with a high clay content can generally store much more P than sandy soils) and past land management practices. Temporary P storage in the soil may be acceptable only if P sorption analysis demonstrates that the soil has storage capacity, the soil profile is at least 0.5 m deep, and the land is used for crop or pasture production. Under these conditions, it may be possible to apply P at rates that provide up to 3–4 years crop requirements on the understanding that the excess P will be removed by plant harvest before more is added.

TABLE 11 Approximate nutrient removal rates for various crops and crop yields

Crop	DM nutrient content (kg/t)[a]			Yield range (DM t/ha)[b]	Nutrient Removal Range (kg/ha)		
	Nitrogen	Phosphorus	Potassium		Nitrogen	Phosphorus	Potassium
Grazed Pasture[c]	20	3	15		7.1–19.0	0.9–2.2	0.1–0.6
Dry Land Pasture (cut)	20	3	15	1–4	20–80	3–12	15 – 60
Irrigated Pasture (cut)	20	3	15	8–20	160–400	24–60	120–300
Lucerne Hay (cut)	31	3	25	5–15	155–465	15–45	125–375
Maize Silage	22	3	20	10–25	220–550	30–75	200–500
Forage Sorghum	22	3	24	10–20	220–440	30–60	240–480
Winter Cereal Hay	20	3	16	1–20	200–400	30–60	160–320
Barley	19	3	4	2–5	38–95	6–15	8–20
Wheat	19	4	5	2–5	38–95	8–20	10–25
Triticale	19	4	6	1.5–3	29–57	6–12	9–18
Rice	14	3	4	4–8	56–112	12–24	16–32
Seed Oats	15	3	4	1–5	15–75	3–15	4–20
Grain Sorghum	20	3	3	2–8	40–160	6–24	6–24
Grain Maize	20	3	4	2–8	40–160	6–24	8–32
Chickpea	40	4	4	0.5–2	20–80	2–8	2–8
Cowpea	30	4	20	0.5–2	15–60	2–8	10–40
Faba Bean	40	4	12	1–3	40–120	4–12	12–36
Lupins	45	3	8	0.5–2	22.5–90	1.5–6	4–16
Navy Bean	40	6	12	0.5–2	20–80	3–12	6–24
Pigeon Peas	26	3	9	0.5–2	13–52	1.5–6	4.5–18
Cotton	20	4	8	2–5	40–100	8–20	16–40

a 1 kg/t is equivalent to 1 g/kg, 1000 mg/kg or 1000 ppm. Data in the dry matter nutrient content column (kg/ha) can be used to calculate approximate nutrient removal rates by multiplying by an appropriate dry matter yield (t/ha) for a given location.

b Yields may vary from these ranges (refer to historical data for the region for more accurate estimates).

c The grazed pasture example assumes a liveweight gain of 75–200 kg/ha/yr, with no ammonia volatilisation losses from the grazed animal's manure.

Sources: Bach (2010), DAFF (2012), Birchall et al. (2008), DPI Victoria (2007), Falconer and Bowden (2005), GRDC (2008), Kaiser et al. (2004), National Research Council (2000) and Reuter and Robinson (1997).

8.5.2 Determining Effluent Irrigation Rates

Effluent irrigation rates are generally expressed as ML/ha or mm. The nutrient mass balance equation is used to determine the mass of each nutrient that can be applied. Effluent composition data can then be used to find the appropriate application rate.

For example, effluent might be used to spray irrigate a lucerne hay crop expected to yield 10 t DM/ha. The expected nutrient removal rate, from Table 11, is 310 kg N/ha, 30 kg P/ha and 250 kg K/ha (i.e. 10 t X mid-range nutrient content). The expected N volatilisation rate for spray irrigated effluent is 20% (Section 8.5.1). If effluent is only irrigated onto the land every three years, it might be possible to add an extra 60 kg P/ha (i.e. 2 X 30 kg P/ha removed by the lucerne crop) on the proviso that it will be removed by crop harvest before additional effluent is irrigated. Applying the formula to each nutrient:

N application rate (kg/ha)	=	310 kg/ha + (20% x 310 kg/ha volatilisation losses) + 0 kg/ha safely stored in the soil
	=	310 kg/ha + 62 kg/ha + 0 kg/ha
	=	372 kg/ha
P application rate (kg/ha)	=	30 kg/ha + 0 kg/ha/yr of acceptable losses + 80 kg/ha safely stored in the soil
	=	30 kg/ha + 0 kg/ha + 60 kg/ha
	=	90 kg/ha
K application rate (kg/ha)	=	250 kg/ha + 0 kg/ha/yr of acceptable losses + 0 kg/ha safely stored in the soil
	=	250 kg/ha + 0 kg/ha + 0 kg/ha
	=	250 kg/ha

The amount of nutrient applied from the mass balance equation can be used to determine the sustainable annual application rate for manure or effluent based on its N, P and K content. The nutrient producing the lowest application rate, in this case P, determines the maximum average annual application rate.

More information on calculating spreading rates is provided in the Piggery Manure and Effluent Reuse Glovebox Guide 2015.

TABLE 12 Analysis results for effluent

Element	Units	Raw effluent[a]	Final pond effluent[a]	Pond effluent[b]	Range for pond effluent[b]
Total solids	mg/L	49,500	3623	7900	1100–44300
Volatile solids	mg/L	–	1809	1640	480–5290
pH		6.7	8.0	8.0	7.0–8.7
Total-N or (Total Kjeldahl N)	mg/L	2175	(384)	584	158–955
Ammonium N	mg/L	1800	249	144	25–243
Total P	mg/L	850	44	69.7	19.3–175.1
Ortho-P	mg/L	–	28.5	16.3	2.4 – 77.9
K	mg/L	618	–	491	128–784
Sulfur	mg/L	–	22	–	–
Sulphate	mg/L	69	26	47.6	13.3–87.2
Copper	mg/L	2.43	–	0.09	0.00–0.28
Iron	mg/L		–	0.56	0.09–1.61
Manganese	mg/L		–	0.02	0.00–0.05
Zinc	mg/L		–	0.47	0.16–1.27
Calcium	mg/L		–	20.6	7.3–41.2
Magnesium	mg/L		–	25.0	6.6–72.3
Sodium	mg/L		603	399	41–1132
Chloride	mg/L		810	19.1	3.6–34.4
EC	dS/m	10.1	–	6.4	2.5–11.7

DEEDI = Department of Employment, Economic Development & Innovation, Qld, TKN = total Kjeldahl nitrogen.

a Kruger et al (1995) – samples from piggeries in New South Wales, Queensland and Western Australia.

b Unpublished data – samples from 10 piggeries in southern Queensland.

8.5.3 Determining Manure Spreading Rates

Manure spreading rates are generally expressed as t/ha. Once the nutrient mass balance equation has been used to determine the spreading rate for each nutrient, data for the manure composition can be used to find the target spreading rate.

Using data from the example given in Section 8.5.2, spent bedding compost might be spread on land used to grow a lucerne hay crop expected to yield 10 t DM/ha and remove 310 kg N/ha, 30 kg P/ha and 250 kg K/ha. The expected N volatilisation rate for compost spreading is 10% (Section 8.5.1). Because manure can be spread at rates that add several years' nutrients in one application, providing there is a plan to remove the applied nutrients, no allowance is made in this example for additional P storage.

Applying the formula to each nutrient:

N application rate (kg/ha)	=	310 kg/ha + (10% x 310 kg/ha volatilisation losses) + 0 kg/ha safely stored in the soil
	=	310 kg/ha + 31 kg/ha + 0 kg/ha
	=	341 kg/ha
P application rate (kg/ha)	=	30 kg/ha + 0 kg/ha/yr of acceptable losses + 0 kg/ha safely stored in the soil
	=	30 kg/ha + 0 kg/ha + 0 kg/ha
	=	30 kg/ha
K application rate (kg/ha)	=	250 kg/ha + 0 kg/ha/yr of acceptable losses + 0 kg/ha safely stored in the soil
	=	250 kg/ha + 0 kg/ha + 0 kg/ha
	=	250 kg/ha
Manure application rate (t/ha)	=	target nutrient application rate (kg/ha) / (nutrient concentration in manure (g/kg)

Table 13 and Table 14 show analysis results for pond sludge and spent bedding. These vary widely and a representative sample should be analysed before the main spreading event. DAFF (2010) provides a single analysis result for compost produced from pig mortalities composted with sawdust. On a wet weight, this contains 1.28% N, 0.22% ammonia-N, 0.27% P and 0.28% K.

From the data for straw bedding in Table 14, the compost might contain 0.8% N, 1.1% P and 1.8% K, which can be expressed as 8 kg N/t, 11 kg P/t and 18 kg K/t. Dividing the target nutrient application rates (kg/ha) by the nutrient content of the compost (kg/t) gives the ideal spreading rate for each nutrient i.e. 43 t /ha for N (i.e. 341 kg N/ha / 8 kg N/t), 2.7 t/ha for P (i.e. 30 kg P/ha / 11 kg P/t) and 13.9 t/ha for K (i.e. 250 kg K/ha / 18 kg K/t). In this case, P is the limiting nutrient and controls the overall spreading rate. Applying two years P at once achieves a practical spreading rate of 5.4 t/ha while not over-applying N and K. N and K will need to be applied to ensure the planned crop yield is achieved.

If analysis result is given as %, multiply by 10 to find g/kg or kg/t.

If analysis result is given as mg/kg, divide value by 1000 e.g. 3,000 mg/kg = 3 g/kg or 3 kg/t.

TABLE 13 Piggery pond sludge analysis results

Element	Effluent at Work[a]	Wang et al. (2006)[b]	DEEDI data[c]	
			Average	range
Total solids	–		13.1% wet basis	6.9–17.1% wet basis
Volatile solids	–		6.9% wet basis	5.3–9.5% wet basis
pH	7.3		–	–
C	–	12–13%	28.1%	22.5–37.1%
Total N or (Total Kjeldahl N)	(2617) mg/L	1.7–2.4%	3.41%	2.84–4.02%
Ammonium N	1156 mg/L	1100 mg/kg	2582 mg/kg	1472–4422 mg/kg
Nitrate-N	–	750–1100 mg/kg	–	–
Total P	1696 mg/L	2.8–3.8%	4.69%	2.83–5.9%
Ortho-P	1082 mg/L		–	–
K	–	6100–8400 mg/kg	0.75%	0.27–1.33%
Sulphur	–	0.58–0.61%	1.99%	1.53–3.08%
Copper	25 mg/L		1.02%	3.43–1.82%
Iron	–		1.17%	0.52–2.21%
Manganese	–		1050 mg/kg	786–1389 mg/kg
Zinc	–		3188 mg/kg	2184–3698 mg/kg
Calcium	2210 mg/L		7.08%	4.28–10.4%
Magnesium	–		1.93%	1.0–3.19%
Sodium	108 mg/L		0.52%	0.15–1.40 %
Selenium	–		0.59 mg/kg	0.07–2.41 mg/kg
Chloride	232 mg/L		–	–
EC	8.5 dS/m		–	

DEEDI = Department of Employment, Economic Development & Innovation, Qld

a Kruger et al. (1995) – samples from piggeries in New South Wales, Queensland and Western Australia.

b Two samples of sludge.

c Unpublished data – samples from 10 piggeries in southern Queensland.

TABLE 14 Spent bedding Analysis results

	Unit	Straw[1]	Straw[2]	Rice Hulls[1]	Sawdust[3]
Dry Matter	% wb	58.4 (36–82)	52 (26–93)	64 (47–79)	59.2 (50–79)
pH		6.8 (5.7–8.5)	–	7.1 (7–7.3)	6.3 (6.2–6.3)
Total N or TKN	% db	0.8 (0.2–1.3)	2.9 (1.7–4.5)	0.7 (0.1–1.6)	0.9 (0.6–1.3)
Ammonium N	% db	0.5 (0–1.2)	–	0.3 (0.1–0.5)	0.6 (0.4–1)
Total P	% db	1.1 (0.2–2.5)	1.2 (0.5–2.6)	0.9 (0.6–1.3)	1 (0.4–1.3)
Ortho-P	% db	0.4 (0.2–0.6)	–	0.4 (0.3–0.6)	0.4 (0.2–0.5)
K	% db	1.8 (0.6–2.8)	2.0 (0.9–3.8)	1.8 (1.2–2.1)	1.8 (1.6–1.9)
Sulphur	% db	0.4 (0.1–0.7)	0.6 (0.4–1.0)	0.4 (0.3–0.5)	0.5 (0.4–0.5)
Copper	% db	0 (0–0.1)	0.01 (0–0.05)	0 (0–0)	0 (0–0)
Iron	% db	1.3 (0.1–3.2)	0.4 (0.09–1)	1 (0.7–1.6)	1.1 (0.5–1.6)
Manganese	% db	0.1 (0–0.8)	0.04 (0.02–0.06)	0.2 (0–0.8)	0.3 (0–0.8)
Zinc	% db	0.2 (0–0.4)	0.1 (0.03–0.4)	0.1 (0–0.3)	0.1 (0.1–0.2)
Calcium	% db	1.9 (0.4–3.1)	2.5 (0.9–5.4)	1.4 (1–2.1)	2.4 (2.1–2.7)
Magnesium	% db	0.7 (0–1.8)	0.04 (0.02–0.06)	0.4 (0–0.6)	0.4 (0 - 0.7)
Sodium	% db	0.4 (0.1–0.7)	0.7 (0.2–1.8)	0.3 (0.1–0.4)	0.4 (0.4–0.5)
Chloride	% db	0.8 (0.3–1.3)	–	0.6 (0.4–0.8)	0.7 (0.4–1.1)
EC	dS/m	11.7 (6.6–15.6)	–	9.6 (9.2–10)	13 (12.6–13.4)

Notes: Data provided as average and range (in brackets).

Nutrient contents based on a combination of fresh, stockpiled and composted spent bedding.

Sources:
1 Black (2000); and Nicholas et al. (2006).
2 Craddock et al. (2011).
3 Nicholas et al. (2006).

8.6 Practical Effluent Reuse

To gain the best value from the nutrients in effluent these need to be applied evenly and at rates and times that optimise nutrient uptake by plants which also minimises leaching and runoff losses. Care needs to be taken so as not to cause odour nuisance for nearby sensitive land uses like houses, schools and public areas. Effluent can also be used to provide moisture for composting manure.

8.6.1 Managing the Nutrients in Effluent

The nutrient balance principles that are the foundation for sustainable effluent reuse are detailed in Section 8.5. Effluent cannot be applied at rates that meet the crop water requirements as this will oversupply nutrients.

The composition of effluent varies widely between piggeries and at individual piggeries depending on weather and other conditions. Table 12 shows the variation in analysis results from different sources. Analysing a representative sample of effluent just before the main reuse period helps in making good management decisions. Effluent can be applied up to the nutrient limited application rate.

Often this will be P and additional N may need to be applied to meet crop needs. This is important as sub-optimal N levels will compromise plant growth and nutrient uptake. Supplementary irrigation may also be desirable to optimise plant growth.

Salt in effluent may be a constraint and cause leaf burn, yield reductions and soil degradation. To manage elevated sodium (Na) and chloride (Cl) in the effluent:

- Dilute the effluent;
- Irrigate with clean water after effluent irrigation to remove salt from plant leaves and flush salts through the soil;
- Apply effluent at low rates;
- Rotate the land used for effluent between years;
- Apply gypsum to sodic soil; and/or
- Grow salt tolerant plants if necessary.

8.6.2 Timing of Effluent Irrigation

The timing of effluent irrigation will often be driven by the need to partially empty the ponds so they are ready to store future rainfall. Fortunately this generally coincides with the wet season when the crops are actively growing and taking up nutrients. Effluent applications should never raise the soil moisture content above field capacity. The application rate must be controlled to ensure runoff does not occur, the exception being surface flow irrigation systems with terminal ponds. Runoff captured in terminal ponds should be irrigated as soon as soil conditions suit so the ponds are ready for the next irrigation event.

Effluent should not be irrigated onto human food crops that are eaten raw or with minimal processing within four weeks of harvest. To protect livestock from pathogen risks, a withholding period of at least 21 days is recommended for paddocks that have been irrigated with effluent.

Effluent should not be irrigated under heavy cloud, if significant rain is forecast or on windy days. Nor should it be irrigated early in the morning or late in the afternoon when the atmosphere is heavy and dispersion hindered.

8.6.3 Effluent Reuse Methods

To minimise the likelihood of blockages, pipelines with a diameter of at least 150 mm should be used to convey effluent to the reuse area.

A wide range of methods are used to irrigate effluent. These include:

- Spray irrigator
- Travelling drip irrigator
- Surface flow
- Tanker.

Applying effluent to land using a pipe or hose distributes effluent very unevenly and therefore is not an acceptable reuse method.

The most suitable irrigation method in a given situation depends on:

- Topography – slope and uniformity
- Crop type
- Soils
- Costs – capital, labour and energy
- Shape of reuse area
- Prevailing seasonal conditions.

Spray irrigation or travelling drip irrigation is generally preferred to surface irrigation because they:

- Have reduced potential for runoff and subsequent collection problems
- Are more likely to apply effluent uniformly
- Can apply effluent at low rates, allowing for regular, smaller applications that more closely match water and nutrient applications with crop uptake
- Can be used on lighter soils or sloping sites.

Small travelling irrigators generally operate at higher pressures than pivot and lateral move irrigators, which means a higher operating cost per unit of effluent applied. Photograph 37 shows a travelling spray irrigator. To minimise risk of nuisance for neighbours, avoid spray irrigating under still conditions, at night, on weekends or during holiday periods when neighbours are more likely to be at home. High-pressure spray irrigators (see Photograph 38) are unsuitable for effluent irrigation because they produce small droplets that can drift.

Photograph 37 Travelling spray irrigator

Photograph 38 Gun spray irrigator

Pipelines for pumping effluent to irrigators should have a diameter of at least 50 mm, 75 mm for pipeline lengths exceeding 100 m or where greater head is involved. Underground pipes should be at least 600 mm below the ground surface to prevent damage from vehicle movements.

Surface irrigation methods only suit sites with an even grade, and must be designed and equipped to achieve uniform effluent applications. This often requires measures such as laser grading and the provision of properly designed flow control systems. These methods are unsuitable for sandy or sandy-loam soils, since effluent passes through these soils too quickly. They are also unsuitable for duplex soils with sandy or sandy-loam topsoil since effluent passes through this layer more quickly than through the heavier subsoil, and then moves laterally over the subsoil layer. A higher standard of management will be needed if effluent is irrigated on steep slopes (>10%) or highly erodable land.

A tanker can be used to spread small amounts of effluent in close proximity to the piggery. However, this is a very time consuming method making it is unsuitable for larger effluent volumes or big reuse areas.

Table 15 provides a comparison of various spray and surface irrigation methods.

TABLE 15 Comparison of irrigation methods

Irrigation Method	Typical Area Range (ha)	Typical Operating Pressures (kPa)	Site Slope Limitations	Typical Application Rates (mm/hr)	Comparative Costs			Uniformity of Application
					Capital	Labour	Energy	
Sprinkler								
Handshift	<10	200–400	<10%	3–10	Low	v high	medium	high
Powered side toll	20–50	200–400	<3%	3–10	medium	medium	medium	high
Travelling irrigator	8–50	400–650	<7%	5–25	medium	high	high	med/high
Centre pivot	40–100	100–300	<2%	variable	high	low	low	v high
Lateral move	50–200	100–300	<2%	variable	high	low	low	v high
Surface Systems								
Border check	-	10–50	0.1–1.0%	5–10	low	medium	-	low
Contour ditch	-	10–50	1.0–7.0%	5–10	low	medium	-	low
Furrow	-	10–50	0.05–1.0%	5–10	medium	high	-	medium
Gated pipe / layflat fluming	-	10–100	0.05–1.0%	5–10	medium	high	-	medium

Skerman (2000) adapted from Lott and Skerman 1995.

8.7 Practical Manure Reuse

Reuse of manure and compost can deliver a range of benefits including improved:

- Soil structure
- Soil water holding capacity
- Soil organic matter levels
- Improved plant growth.

Good siting, design and management are needed to minimise the risk of environmental impacts.

For practical and agronomic reasons, it can be beneficial to apply manure containing several years worth of nutrients to an area at each spreading. Spreading at higher rates less frequently can help to:

- Spread manure and effluent more evenly – some spreading equipment needs a minimum application rate to achieve even spreading
- Overcome some nutrient availability issues – not all nutrients will be available immediately after spreading. Applying several years of nutrients at once helps to ensure sufficient nutrient is available for plant uptake. However, high application rates pose a leaching and runoff risk and can result in excessive crop growth; consult your agronomist about appropriate rates
- Minimise the need for regular soil disturbance that may damage soil structure
- Minimise dissolved nutrient losses
- Reduce costs associated with more frequent spreading at lower rates.

8.7.1 Timing of Manure and Compost Spreading

The ideal time to spread manure and compost depends on:

- The timing of cropping cycles and management practices (e.g. cultivation to incorporate manure or compost)
- Manure or compost maturity
- Soil moisture conditions
- Wind conditions.

In broadacre cropping situations, manure is generally spread prior to planting the crop, with the cultivation associated with the seeder pass incorporating the manure. On soils with low background nutrient levels, spreading manure just before sowing in some circumstances, can result in less vigorous and lower yielding crops than if inorganic fertilisers had been applied. This can occur because the nutrients in the manure are less available or less accessible for uptake by the plant roots.

This is more common on soils with low background nutrient levels. N and P are present in manure and compost in both inorganic and organic forms; the latter have to be mineralised into inorganic forms to be available for plant uptake. Most of the K in manure is in the inorganic form and available for uptake.

Applying manure 4–6 months before crop establishment allows time for nutrients to mineralise from the organic matter and reduces the risk of nitrogen drawdown which may occur after manure spreading. Drawdown occurs when soil micro-organisms take nitrogen from the soil to use in breaking down the fresh manure. The downside is that there is a risk of increased nitrogen losses if manure is applied too far ahead of crop planting, particularly if there is minimal incorporation of the manure. Nitrogen drawdown is likely to be less of a concern if the manure is composted before spreading, and in soils with reasonable background nutrient levels, allowing manure to be spread closer to planting.

To reduce nitrogen losses from the applied manure, it is often recommended that manure is spread as close as possible to planting, cultivation, or just prior to a forecast rainfall event, to incorporate the manure quickly and maximise nitrogen retention.

Accessibility of manure nutrients by plant roots can also be an issue, resulting in poorer crop vigour. In modern broadacre cropping systems, manure is generally broadcast prior to crops being sown using low disturbance, no-till (e.g. knife points and press wheels) or zero-till (e.g. disc seed systems) seeding equipment. This results in little incorporation of manure at planting and minimal manure (and therefore nutrients) in the seed row in close proximity to the developing roots of germinating seedlings. If the paddocks will be ploughed for seeding, spreading manure beforehand will allow it to be incorporated into the soil.

In some soils, reductions in crop vigour are phosphorus-related, and can be overcome by using a "starter" application of inorganic P fertiliser in the seed row, in addition to the application of manure prior to planting. Depending on the background P levels in the soil, the fertiliser rates may be significantly lower than conventional application rates. Testing the levels of available nutrients in paddocks planned for manure or compost spreading is recommended. Recent improvements in soil testing technologies, such as DGT (Diffuse Gradients in Thin Films) tests have increased confidence in making decisions on whether inorganic fertiliser should be applied in conjunction with manure applications.

Manure spreading should be avoided under windy conditions, especially if the wind is blowing towards nearby houses or public use areas.

To protect grazing livestock from pathogen risks, a withholding period of 21 days applies to paddocks that have been spread with manure or compost.

8.7.2 Manure Spreading Options

Manure spreaders are designed for spreading relatively dry, aged and composted solids. The amount of material for spreading, the quality of the material and the proposed spreading rate all determine which spreader will be most suitable. The cost and efficiency of spreading influences the value of the manure as a fertiliser.

Purpose-built manure spreaders are typically categorised as rear or side discharge systems with capacities of 1–20 t. The rear discharge spreaders are usually equipped with a moving conveyor belt, moving floor chain or hydraulic push door that transfers manure to horizontal or vertical beaters, or spinning discs. A spreader with horizontal beaters is shown in Photograph 39 and Photograph 40 while a spinning discs spreader is shown in Photograph 41 and Photograph 42. Side discharge systems use a horizontal auger to transfer manure to the spinning discs or beaters. Both discharge systems can be self-propelled (i.e. mounted on a truck or tractor chassis) or towed behind a tractor as an independent unit.

Conventional fertiliser spreaders typically use a rear door to control the rate of fertiliser falling onto the spinning discs (to ensure accurate, uniform application rates). Chunks of spent bedding can become trapped in the rear door and prevent manure from being uniformly spread over land.

Conventional fertiliser spreaders are unsuited to applying fresh spent bedding or other inconsistent materials

The best coverage is achieved by using belt or moving floor-fed horizontal disc spinners with aged or composted manure. Belt-fed spreaders are less effective with inconsistent or high moisture (>35% moisture) manure like fresh spent bedding. While side-delivery spreaders use more power, they are suitable for all manure. Horizontal beater spreaders also suit all manure but spread at higher rates.

Operator efficiency influences where manure is spread on the paddock and at what rate. This is especially relevant for spreaders where operation speed influences the rate applied. Ensuring that consistent spacings are achieved between spreader passes is important for covering the whole paddock evenly. GPS guidance results in a more accurate and efficient spreading operation by reducing overlap and missed areas compared with estimation by the operator.

Photograph 39 Horizontal beater manure spreader

Photograph 40 Horizontal beater manure spreader applying manure

Photograph 41 Spinning discs spreader

Photograph 42 Spinning discs spreader applying aged manure

There are a number of features to consider when selecting a spreader. These include:

- Spreading pattern and width – to ensure an even spreading pattern and application rate are achieved. Some spreaders have an effective spreading width of 2 m while some of the European specialised manure spreaders have a spreading width of up to 10 m. A greater spreading width reduces soil compaction
- Horizontal versus vertical beaters – vertically mounted beaters generally spread over a larger area with each pass, throwing manure beyond the width of the spreader. Horizontal beaters usually only spread about the width of the spreader. The beaters break up the lumps enhancing spreadability of lumpy or high moisture spent bedding

- Conveyor belt versus moving floor chains – movement of the manure to the back of the spreader can be achieved using a conveyor belt or chain and slats. These can be either hydraulic or PTO driven. Conveyor belts may need to be replaced more often as the belt wears more rapidly than the chains. Floor chains offer advantages over belts when spreading inconsistent or high moisture manureFloor chain systems tend to have less problems with manure bridging when delivering manure to the beaters/spinners compared to conveyor belts. (Bridging occurs when moist manure clumps together to form a "bridge" with a space underneath, stopping the feed of manure to the spreading devices)
- Beater/spinner design – the rotation speed of the beaters will affect the width of spread and application rate. Also consider the height at which the beaters are positioned on the spreader. Generally the greater the height above the ground the greater the width of spread. The compromise is that high spinners or beaters also mean a high centre of gravity on the machine which can result in instability on uneven ground
- Spreader power requirements – check the power requirements of the spreader in relation to the tractor or truck
- Most spreaders need a minimum application rate of about 5 t/ha to achieve an even spread, and this may be higher for some spreaders. Fresh lumpy spent bedding does not spread well and is likely to be uneven at rates of less than 10 t/ha
- Load capacity – larger capacity spreaders offer better efficiency by minimising time between loads. Spreader capacity ranges from under 3 m^3 to 15–30 m^3 models. Some spreaders can be fitted with extension side ("hungry boards") to increase capacity
- Design of sides – vertical sides are preferable to angled sides as these are less likely to result in manure "bridging"
- Engineering – under-engineered spreaders may require increased maintenance (e.g. due to bearing failures, bent shafts) compared to those with more robust engineering.

8.7.3 Off-Site Utilisation of Manure and Compost

Many large deep litter piggeries, and some smaller ones, need to send at least part of their manure or compost to off-site buyers due to lack of suitable land. Appendix 3 can be provided to people buying manure to ensure they are aware of their duty of care. To avoid manure spillage and associated odour or dust concerns, loads of manure being transported along public roads should always be covered.

8.7.4 Valuing Manure and Compost

Appendix 4: Manure Valuation Pro-Forma provides a method, using fertiliser price and manure nutrient content, to place a value on manure.

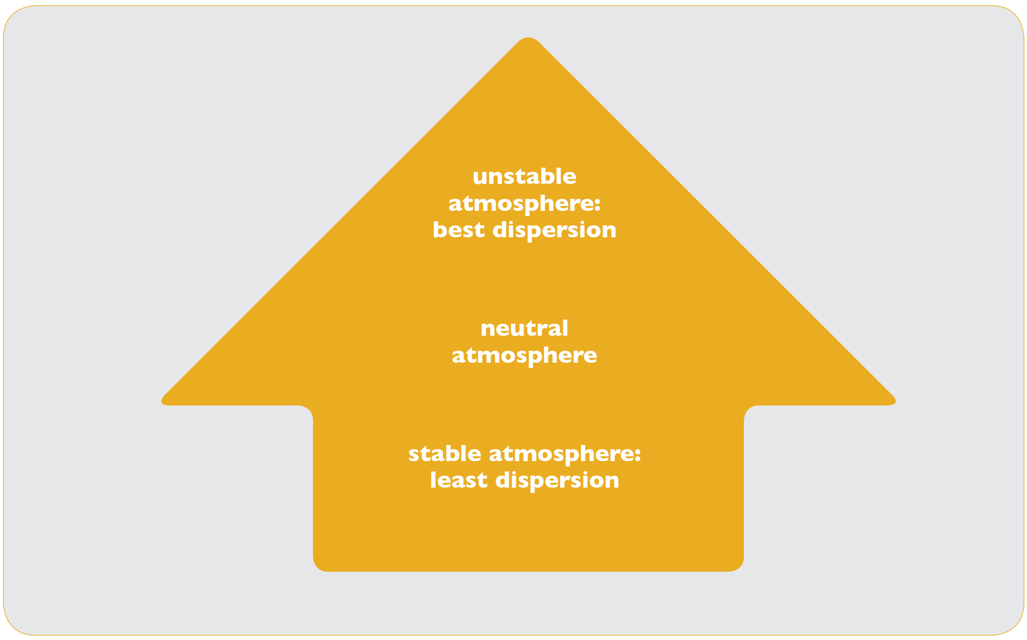
8.8 Odour Control

There is some flexibility in the timing of effluent irrigation and manure or compost spreading which provides an opportunity to control odour emissions. This requires a basic understanding of atmospheric conditions since these drive the dispersion of odours. The different types of atmospheric conditions are:

- **Unstable atmosphere:** typically the atmosphere is unstable on warm sunny days when hot eddies of air rise from the land surface and cause significant mixing of the atmosphere. Odours are rapidly dispersed and carried upwards, quickly reducing odour intensity away from the source. Because these conditions promote rapid dispersion they are ideal for most odour generating activities.
- **Neutral atmosphere:** this occurs on heavy overcast days when there is only moderate odour dispersion.
- **Stable atmosphere:** a stable atmosphere occurs on cold, still clear nights when the air at the land surface stays cool and remains trapped below an inversion layer. Little atmospheric mixing occurs below this layer and there is little odour dispersion. Odours remain at a relatively high intensity at some distance from the source. These conditions are unsuitable for undertaking activities that will release significant odour.

Figure 11 shows the odour dispersion hierarchy.

FIGURE 11 Odour dispersion hierarchy



Effluent and manure reuse should only occur when the prevailing weather conditions are unlikely to result in odour and dust nuisance for nearby residents. Consider the wind direction and strength, the time of day and the atmospheric stability. A plan showing the location of all nearby neighbours and a simple wind vane will help to show which neighbours are at risk of odour nuisance from effluent or manure reuse on particular areas. It is useful to understand the relative sensitivities of different neighbours to odour.

It can be worthwhile to develop an annual reuse plan that takes into account seasonal predominant wind directions, rainfall patterns and cropping plans. Different paddocks might be selected for reuse at different times of the year depending on risk.

To reduce odour nuisance at neighbours, spread manure or compost and irrigate effluent:

- Frequently to minimise the likelihood of large, odour generation events
- Evenly
- From mid-morning when the air is warming, rather than late in the evening
- Then as soon as possible harrow, disc or chisel plough to incorporate manure into the soil (if this is practical)
- Spray effluent as close to the ground as possible.

Do not spread or irrigate:

- Dry manure or compost that will result in dust being blown towards neighbours, particularly under windy conditions
- If the wind is blowing towards a nearby house or public area
- If rain or heavy cloud are expected
- Just before or on weekends or holiday periods when neighbours are more likely to be home, particularly if close to a public area.

Also:

- Eliminate all wet patches in drains and yards of outdoor piggeries
- Train all staff in odour dispersion
- Advise neighbours before spreading manure or irrigating effluent near them even if winds won't blow towards them. Also contact neighbours if conditions change and they are more likely to be affected. This makes them aware of the source and lets them know how long the odour is likely to last.

9 Manure Management in Rotational Outdoor Piggeries

9.1 Introduction

Rotational outdoor piggeries are systems in which pigs are kept outdoors in small paddocks that are used in rotation with a crop-pasture phase. The manure nutrients, which are deposited onto land by the pigs, tend to be spread unevenly over the paddocks due to the distinct dunging pattern of the pigs and can accumulate to very high levels in a short time frame. Good land management is needed to prevent environmental impacts; suitable stocking rates and length of pig phase, erosion prevention measures, active management to encourage more even manure dispersal, an appropriate land use rotation and regular soil testing are necessary to reduce the likelihood of environmental impacts. APL's National Environmental Guidelines for Rotational Outdoor Piggeries detail recommendations for manure management in these systems.

9.2 Properties of Land for Rotational Outdoor Piggeries

Land management is easier if an outdoor piggery:

- Is located in an area with a lower annual rainfall (e.g. less than 760 mm) and lower storm intensity
- Has sufficient land available
- Can provide a 100 m wide VFS between the piggery and any watercourse, an 800 m wide buffer to a major water supply storage and a 20 m wide buffer to a bore
- Has suitable separation distances to sensitive land uses. These should be at least:
  - 750 m to a town
  - 500 m to a rural residential area
  - 250 m to a rural dwelling.
- Comprises of soils that are well drained but which contain sufficient clay to retain nutrients in the root zone (Photograph 43). Sites with light soils are subject to wind erosion (and nutrient removal) when groundcover is denuded and to leaching. Sites with heavy soils tend to hold nutrients better but may become boggy and provide unsuitable paddock conditions during wet weather. Fine-textured soils with a high clay and silt content may be vulnerable to compaction, particularly in wetter locations
- Is flood-free and has gently sloping land to minimise the likelihood of local flooding.

Photograph 43 Rotational outdoor piggeries work on gently sloping sites with soils that can retain nutrients

9.3 Management Principles for Environmentally Sustainable Rotational Outdoor Piggeries

The factors important to good land management in rotational outdoor piggeries include:

- Nutrient budgeting: rotational outdoor piggeries operate with a pig phase in which nutrients are added to the soil, and a crop/forage/pasture phase in which nutrients are harvested. Nutrients in the soils of an area need to be restored to sustainable levels before the next pig phase commences
- Encouraging even spreading of manure nutrients
- Adopting strategies to minimise uncontrolled movement of nutrients from pig paddocks, in particular retention of groundcover to minimise nutrient losses via soil erosion
- Undertaking routine environmental monitoring, particularly soil monitoring during the pig and cropping phases of the rotation (see Section 10.3).

9.4 Nutrient Budgeting

Gross paddock N, P and K accumulation rates depend mainly on the stocking density and the length of time that pigs stay on a land area. Recent APL-funded research on two commercial Australian rotational outdoor piggeries showed that nutrients accumulated to very high concentrations within 6–12 months of commencement of the pig phase. Wiedemann (2014) found that the pigs were adding some 300–600 mg N/ha/yr and 100–200 kg P/ha/yr. Soil nutrient concentrations also varied widely within each paddock. Elevated nitrate-N and P levels in the topsoil and subsoil, and evidence of nitrate-N leaching below the crop root zone, represented environmental risks to both surface water and groundwater. Soil testing should be used as a basis for determining when to move pigs from a particular land area. Following the pig stocking phase, a suitable crop-pasture rotation is needed to utilise accumulated N, P and K.

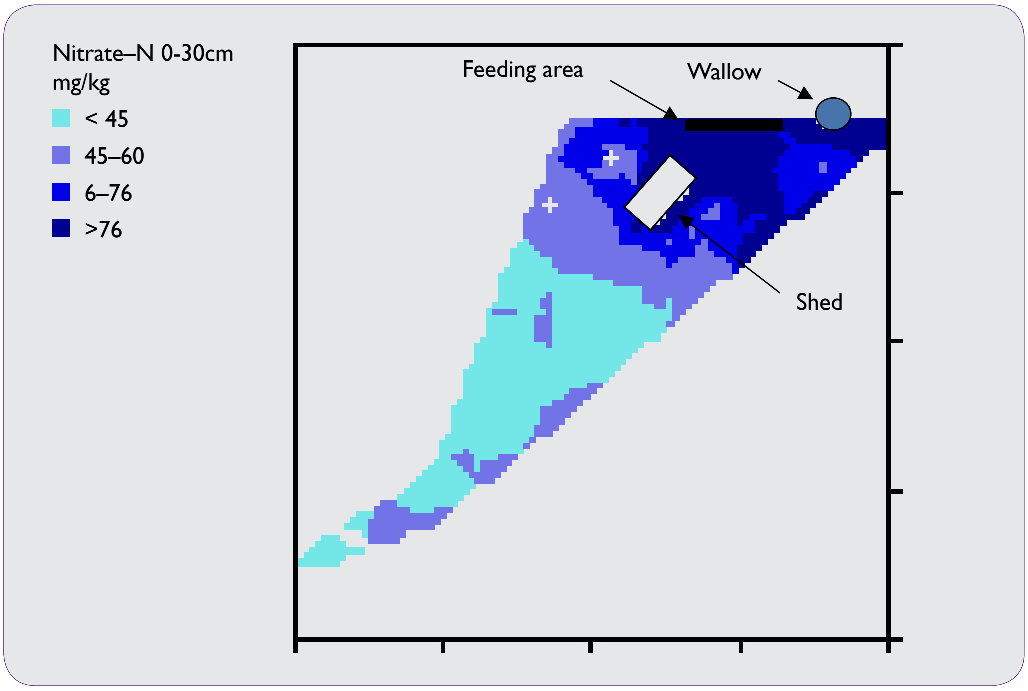
The nutrient balance principles for a rotational outdoor piggery are the same as for other reuse areas (see Section 8.5), although it is very important to remember that nutrients are unlikely to be spread evenly so this can only ever be a planning guide. It appears that ammonia-N volatilisation losses from outdoor systems are around 20–25%, with higher loss rates if the soil has a high N concentration. More information on calculating a nutrient balance for a rotational outdoor piggery is provided in the Glovebox Guide.

9.5 Encouraging Even Spreading of Manure Nutrients

Without active management, manure is not spread evenly across the paddocks of rotational outdoor systems. Figure 12 shows the pattern of nitrate-N distribution in a typical dry sow paddock which reflects the distinct dunging pattern; nutrients are mainly deposited between the shelters and the feeding area. This increases the risk of nutrient overloading, leaching and/or runoff from this area and has implications for the growth of future crops.

Moving pig housing, feeders and other facilities regularly during the stocked phase changes the dunging pattern and helps to spread nutrients more evenly. When purchasing shelters and feeders choose readily movable designs and plan to relocate these at least every six months for the breeder herd and at least every three months for the grower herd, preferably more frequently. Regularly moving facilities mays also reduce soil compaction on vulnerable sites.

FIGURE 12 Nitrate-N distribution – dry sow paddock



Galloway and Wiedemann (2011)

9.6 Minimising Uncontrolled Movement of Nutrients from Pig Paddocks

Stormwater runoff from pig paddocks may transported eroded soil and nutrients attached to the soil or dissolved in the water. The removal of soil from paddocks also reduces the productive capacity of that land. Groundwater quality may also be compromised through nutrient leaching through the soil. Managing soil nutrient levels and erosion prevention are the keys to minimising these impacts. Strategies to minimise uncontrolled movement of nutrients from pig paddocks include:

- Maintaining groundcover over the paddock areas. Groundcover prevents soil erosion and minimises dust releases from paddocks. It can be very difficult to maintain groundcover as pigs can quickly denude an area. It is very important to start each pig phase on a well-established grass sward, preferably a rhizomatous species, or other resilient vegetative cover. Lighter stocking densities and shorter pig phases may help in retaining vegetation
- A land use rotation that does not allow manure nutrients to accumulate to excessive levels and a crop/forage/pasture phase designed to remove the nutrients added by the pigs
- Regular soil testing that is used to determine when to move pigs off a land area
- Provision of a good, hardy VFS and/or bank and possibly terminal pond/s below the piggery
- Constructing wallows on soils that minimise nutrient leaching, or lining of wallows with clay. After the pig phase, wallows should be remediated by ripping; applying gypsum as needed; and proper refilling and levelling.

9.7 Further Information

APL has produced the Outdoor Piggery Fact Sheet Series which includes the following fact sheets:

- Design and Management of Outdoor Free Range Areas for Pigs (Australian Pork Ltd 2011a)
- Sustainable Reuse of Piggery Effluent (Australian Pork Ltd 2011b)
- The Use of Electromagnetic Technology to Determine Nutrient Distribution in Free Range Pig Areas (Australian Pork Ltd 2011c)
- Promoting More Even Distribution of Manure Nutrients in Rotational Outdoor Piggeries (Australian Pork Ltd 2012c)
- Land and Water Protection Measures for Rotational Outdoor Piggeries (Australian Pork Ltd 2012b)
- Developing a Nutrient Management Plan for a Rotational Outdoor Piggery (Australian Pork Ltd 2012a)
- Soil Monitoring for Rotational Outdoor Piggeries (Australian Pork Ltd 2012d).

These are available on the APL website (www.australianpork.com.au): http://australianpork.com.au/industry-focus/environment/outdoor-production.

There is also an environmental component in the APIQ✓® Free Range Standards, see www.apiq.com.au.

10 Risk Based Environmental Monitoring

10.1 Introduction

The NEGP provide recommendations for monitoring the soils of reuse areas. The monitoring frequency depends on the level of risk. The NEGP also recommend effluent and manure analysis parameters that can be used to determine sustainable application rates. Since the NEGP were published, these soil and land monitoring recommendations have been modified for application to rotational outdoor piggeries. For all piggery systems, the soil analysis results are initially evaluated using indicators of sustainability. This section summarises the recommended monitoring for reuse areas and rotational outdoor piggeries.

10.2 Monitoring for Reuse Areas

Under the NEGP, a risk assessment is used to determine the risk of impacts to soils. Where the likelihood of impacts is low, and at least three years of annual monitoring shows the system is sustainable, sampling and analysis of representative soils from reuse areas at least every three years is suggested. However, nitrate-nitrogen levels should be monitored annually, as nitrogen in this form moves quickly through the soil.

Where there is a medium risk of soil impacts and at least three years of monitoring data shows the system is sustainable, sampling and analysis of soils at least every two years, with annual nitrate-nitrogen monitoring is suggested. Effluent and solids utilised on-site should be analysed annually. This frequency could be reduced if results from several years show stable levels.

Where there is a high risk of soil impacts, annual soil monitoring is suggested. Annual effluent and solids analysed is recommended, although this frequency could be reduced if results from several years show stable levels.

Soil sampling should always occur at the same time of year. The end of the cropping cycle is a good time since nutrients remaining in the soil at this time are vulnerable to leaching. Sampling should not occur immediately after prolonged wet weather. Detailed advice on sample collection is provided in Appendix 4 of the NEGP.

The recommended soil monitoring parameters are given in Table 16. Analysis results should be compared with the sustainability indicator limits. Where soil analysis results exceed these limits, further investigation is triggered to identify whether by-products reuse is sustainable.

TABLE 16 Recommended soil analysis parameters for each sampling depth

Soil test parameter	Depth (down profile)
pH	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone
EC[a]	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone
Nitrate-nitrogen	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone
Available P	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone [b]
P sorption capacity or P sorption index	0–0.6 m OR 0.3–0.6 m OR 0.3 m to base of root zone [c]
K	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone
Organic C	0–0.1 m
Exchangeable cations (calcium, sodium, potassium, magnesium) and cation exchange capacity (CEC)	0–0.1 m 0.3–0.6 m OR 0.3 m to base of root zone

[a] EC_{se} levels in the top soil layers are not intended to be a direct sustainability indicator, but will provide useful agronomic information and provide a guide to soil salt movements.

[b] Only check available P levels annually at 0.3–0.6 m (or base of root zone) if a sandy soil, otherwise every three years.

[c] Measurement of P sorption capacity to 0.6 m (or base of root zone) is desirable before use and every three years after initial application.

Note: Measuring chloride at 0.3–0.6 m (or base of root zone) may also be warranted if further investigations or actions for salinity are required.

10.2.1 Measuring Sustainability

The NEGP provide suggested trigger values to assist in determining if nutrients are being spread at sustainable rates and these provide for preliminary assessment of sustainability. Because soil properties vary widely, trigger values are not always the best measure. Where results for a site exceed the trigger/s further investigation is needed, such as comparison against historical or background data. The ideal site to collect a background sample would be close to the area of interest, with a similar soil type and land use to the reuse area but would not have been spread with piggery by-products. However, depending on past management, these areas may also have different properties compared to their background state. It may be necessary to analyse samples from a number of locations or to use local land and soil management references to interpret the results. Comparison with historical data and trend analysis may also be helpful.

TABLE 17 Nitrate-N concentrations corresponding to a soil solution concentration of 10 mg NO3N/L at field capacity

Soil Texture	Soil gravimetric moisture content at field capacity (g water/g soil)	Limiting soil Nitrate-N concentration (mg NO_3N/kg soil)
Sand	0.12	1.2
Sandy-loam	0.15	1.5
Loam	0.17	1.7
Clay-loam	0.20	2.0
Light Clay	0.25	2.5
Medium Clay	0.35	3.5
Self-Mulching Clay	0.45	4.5

TABLE 18 Suggested trigger levels for investigation for P in topsoil

Clay Content	pH	Colwell P (mg/kg)
< 30%	< 7	31
< 30%	> 7	59
> 30%	< 7	75
> 30%	> 7	85

Notes:

1 These levels do not apply to some soils, e.g. black vertosols, or to high-productivity systems.

2 Under highly productive agricultural systems, these levels are commonly exceeded. Hence, they should be regarded only as trigger values for further investigation or action.

TABLE 19 Rankings for Olsen P in topsoil

Very Low	Moderate	High
<12 mg/kg	12–25 mg/kg	>25 mg/kg

Notes:

1 The ranking of high (>25 mg/kg) could be considered a trigger level for further investigation or action.

2 Under highly productive agricultural systems, these levels are commonly exceeded. Hence, they should be regarded only as trigger values for further investigation or action.

TABLE 20 Rankings for Bray P in topsoil

Very Low	Low	Moderate	High	Very High
<5 mg/kg	5–10 mg/kg	10–20 mg/kg	20–25 mg/kg	>25 mg/kg

Note: Under highly productive agricultural systems, the 'high' and 'very high' levels are commonly exceeded. Hence, they should be regarded only as trigger values for further investigation or action.

TABLE 21 BSES P trigger levels

Clay Content	Guideline (mg/kg)
< 30%	31
> 30%	131

Note: Under highly productive agricultural systems, these levels are commonly exceeded. Hence, they should be regarded only as trigger values for further investigation or action.

TABLE 22 P sorption capacity classifications for different P buffer capacities

Classification	P buffer capacity (mg p/kg)
Very low	< 5
Low	5–10
Moderate	10–15
High	15–25
Very High	> 25

10.3 Monitoring for Rotational Outdoor Piggeries

It is useful to sample and analyse the soil of paddocks before the pigs move onto an area; and also when the pigs leave an area as this helps in managing the crop/forage/pasture phase. As a guide, pig phases should generally not exceed two years in length. For systems with a pig phase that exceeds two years in length, soil monitoring should usually be undertaken at least every two years, although this depends on the risk. Where a risk assessment shows high risk, annual monitoring is warranted. If ongoing monitoring shows that the risk is low, monitoring at three yearly intervals may be justified.

Samples should be collected from random locations in the areas between the shelters and the feeding, watering and wallowing facilities as these areas are likely to have the highest soil nutrient levels and pose the greatest risk to the environment. One composite (bulked) sample per block of paddocks is generally sufficient. If spent bedding is applied to separate reuse areas soil monitoring of these areas may also be warranted. Specific advice on sample collection is provided in the "National Environmental Guidelines for Rotational Outdoor Piggeries".

The analysis parameters and interpretation of soil results is the same as for reuse areas (Section 10.2).

11 Worker Safety

Worker safety must be considered in all aspects of piggery operation. Suitable measures and training are essential. This section addresses limited considerations relating to manure and effluent management, treatment and reuse.

To protect worker safety:

- Avoid entry into enclosed pits or manure storage areas unless wearing suitable clothing and using appropriate personal protection equipment e.g. respirator and safety line. A safety observer should also be in attendance although they should remain outside the possible danger area
- Equip enclosed pits with prominent warning signs e.g. Danger gas, No smoking – no naked flame (Kruger et al. 1995) (This would also apply in the vicinity of covered ponds)
- Prevent access to effluent ponds through fencing. Place prominent warning signs around the perimeter fence of effluent ponds e.g. Danger – Deep Water. Staff should also be trained in the dangers pertaining to working close to deep water
- Design ramps to ponds or pits such that they are wide and structurally stable enough to support service vehicles
- Implement good hygiene practices; effective cleaning; and pest and vermin control and monitoring to reduce the likelihood of health issues
- Use appropriate storage and disposal of toxic substances and containers. Entry of these into the effluent system can disrupt pond function and contaminate land and water after reuse
- Carefully manage feed and feed wastage so as not to encourage vermin breeding (Kruger et al. 1995).

To ensure safe operation, great care needs to be taken with biogas collection systems. Good design and regular inspection and maintenance of the pond cover is necessary to ensure it is always in good condition. Any holes that release gas in an uncontrolled way pose a health, fire and explosion risk. It is important to ensure there is no unauthorised access to the pond and associated equipment. It should carry a prominent warning sign (e.g. Danger – Liquid Manure Storage). A Biogas Safety Management Plan should also be in place. The APL Code of Practice for On-farm Biogas Production and Use (Piggeries) (Australian Pork Ltd 2014) provides complete details.

12 References

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Appendix 1: Pond and Pad Permeability Specifications

Constructing Effluent Ponds

Based on: DAFF (2009): http://www.daff.qld.gov.au/environment/intensive-livestock/piggeries/managing-environmental-impacts/constructing-effluent-ponds

This guide provides quantitative standards to assist the industry in constructing effluent ponds that meet the accepted maximum permeability of 0.1 mm per day.

Because in-situ and laboratory measurement of soil permeability is difficult and relatively inaccurate, rather than relying on permeability standards, this document provides recognised standards for clay lining materials and methods. By applying these standards, an acceptable degree of impermeability should be achieved consistently.

This guide is based on established engineering principles; however, the recommended methods may be revised from time-to-time, as new methods are developed. Proposals involving alternative materials or methods may be submitted to the administering authority for consideration.

Material

The material used to clay-line the ponds must be well-graded impervious material, classified as either CL, CI, CH, SC or GC in accordance with the soil classification system described in Appendix A (Table A1) of Australian Standard 1726.

Note: The classification symbols represent inorganic clays having low, intermediate and high plasticity, clayey sands and clayey gravel, including gravel-clay-sand mixtures, respectively. Furthermore, the lining material must conform with the particle size distribution and plasticity limits in the table below.

TABLE 1 Particle size distribution

AS metric sieve size (mm)	Percentage passing (by dry weight)
75.000	100
19.000	70–100
2.360	40–100
0.075	25–90

TABLE 2 **Plasticity limits on fines fraction, passing 0.425 mm sieve**

Measure	Score
Liquid limit W_L	30–60%
Plasticity index I_p	>10%

If materials complying with the above plasticity limits are not readily available, clays having liquid limits between 60% and 80% may be used as lining material, provided that the clay lining layer is covered with a layer of compacted gravel (or other approved material). The compacted gravel layer should have a minimum thickness of 100 mm to prevent the clay lining from drying out and cracking.

Testing of materials to determine compliance with the above requirements must be carried out in accordance with the appropriate sections of Australian Standard 1289. The administering authority may direct the licensee to provide test results certified by an accredited soils laboratory (accredited by the National Association of Testing Authorities (NATA) or equivalent).

Topsoil, tree roots and organic matter must not be used as clay lining material. Furthermore, any other material, which does not compact properly must not be placed in any of the areas to be clay-lined.

Wherever non-dispersive materials are available, they are to be used in preference to materials shown to be dispersive using the Emerson test, as described in Method 3.8.1 of AS 1289. Note: A Class-8 material is considered to be non-dispersive.

Placement of Material

Effluent ponds capable of storing water up to a maximum depth of 2 m, must be lined with complying material to a minimum total thickness of 300 mm. Ponds capable of storing water at depths in excess of 2 m, must be lined with complying material to a minimum total thickness of 450 mm. This can be achieved by placing the material at the correct moisture content in progressive, uniform, horizontal layers, not exceeding 150 mm in thickness, after compaction.

Under no circumstances is the compacted thickness of clay lining material to be less than the required minimum thickness.

Correct Moisture Content

Prior to compaction, all material used for lining purposes must be conditioned to have a moisture content within the range of 2% wet to 2% dry of the optimum moisture content required to produce the maximum dry density when compacted in accordance with Method 5.1.1 of AS 1289.

As a guide, the required moisture content is as wet as it can be rolled without clogging a sheep's-foot roller. A preliminary assessment of the moisture content can be made by rolling a sample of the material between the hands. If it can be rolled to pencil thickness without breaking, it should be satisfactory.

Compaction

Each layer of material must be compacted to produce either a field dry density of at least 95% of the standard maximum laboratory dry density determined in accordance with Method 5.4.1 of AS 1289, or alternatively, a Hilf density ratio of at least 95% when tested in accordance with Method 5.7.1 of AS 1289.

This degree of compaction may generally be achieved by rolling each layer of material, placed at the correct moisture content, with at least eight passes of a sheep's-foot roller. As a guide, compaction will generally be sufficient when there is a clearance of 100 mm between the drum of the roller and the compacted material.

Sheep's-foot Roller

Sheep's-foot roller specifications for fulfilling compaction requirements:

- The diameter of the drum/s cannot be less than 1 m
- The length of the drum/s must be approximately 1.2 times the drum diameter
- The feet must extend approximately 175 mm radially from the drum and be of the taper-foot type, with a cross-sectional area close to the outer end of not less than 3200 mm^2 and not more than 4500 mm^2
- The number of feet shall be such that their total area close to the outer ends shall be between 5% and approximately 8% of the area of the cylinder, which would enclose all the feet, i.e. a cylinder having a diameter equal to the diameter of the drum plus twice the length of each foot
- The weight of the roller ballast, shall be such that the bearing pressure thus obtained shall be not less than 1750 kilopascals, in accordance with the following formula:
  bearing pressure (kPa) = mass (kg) x 9.81 x 1000 ÷ area of contact of one row of feet (mm^2).

Other types of rollers and configurations may be used provided that the required compaction is achieved.

Test for Adequate Compaction

The administering authority may request compaction testing. Compaction testing must be performed in accordance with AS 1289 and be certified by an accredited soils laboratory or equivalent. A copy of the certified test results are then forwarded to the administering authority.

If the test results fail to comply with the compaction requirements, remedial measures are to be implemented as directed by the administering authority before the pond can be used.

Synthetic Liners

Alternate material and installation specifications relating to the use of synthetic lining materials may be used in lieu of clay lining.

Earth Pad Preparation for Deep Litter Piggeries, Solid Waste Stockpiles and Composting Areas

Based on DAFF (2011): www.daff.qld.gov.au/environment/intensive-livestock/piggeries/managing-environmental-impacts/earth-pad-preparation

1. Clearing and Grubbing

The area where the pad is to be established shall be cleared of all trees, scrub and stumps. All tree roots should be grubbed to a minimum depth of 300 mm below natural surface. All trees, scrub, stumps and roots removed from the pad area should be transported to a location clear of the works area and stockpiled or disposed of to the satisfaction of the landowner.

2. Stripping of Topsoil

Because of its high organic matter content, topsoil is unsuitable for compaction in the pad foundation. Therefore, unless otherwise determined by the administrating authority, all topsoil shall be stripped from the entire surface of the proposed pad area to a minimum depth of 150 mm. The stripped material shall be stockpiled or disposed of clear of the works area to the satisfaction of the landowner.

3. Pad foundation Preparation

Following topsoil stripping and prior to the placement of any fill material, the in-situ foundation should be prepared by the following operations, to produce a satisfactory bonding surface for the placement of subsequent layers of material:

i. Placement and compaction of suitable material into any holes or depressions resulting from the grubbing of tree stumps and roots
ii. Scarifying or ripping with a tined implement, to a minimum depth of 150 mm
iii. Watering to produce the correct moisture content, as specified in clause 6
iv. Compaction in accordance with clause 7.

4. Excavation and Placement of Pad Material

The pad area should be cut and/or filled as required, to produce a smooth, uniform surface.

Provided topsoil stripping exposes a pad foundation material that complies with the suitability requirements specified in clause 5, and further excavation and/or placement of fill are not required to achieve the design pad gradients, levels and dimensions, the pad surface shall be prepared as described above in clauses 3(i) to (iv).

If the pad foundation material exposed following the completion of topsoil stripping does not comply with clause 5, further excavation should be carried out to enable the placement and compaction of a minimum thickness of 300mm (after compaction) of suitable pad material, to produce the design gradients, levels and dimensions.

All fill material placed in the pad shall comply with the suitability requirements specified in clause 5. Following preparation of the pad foundation as described in clause 3 above, all fill material shall be conditioned to the correct moisture content as defined in clause 6, excavated, transported and placed on the pad surface in progressive, approximately horizontal layers, having a uniform thickness of not more than 200 mm prior to compaction.

All unsuitable material excavated from the pad area or external borrow area(s) shall be placed in spoil heaps, clear of the works area, to the satisfaction of the landowner.

5. Materials

5.1 Material Specification

Material shall be considered suitable for placement in the pad, subject to compliance with the following requirements:

- The material shall be classified as either CL, CI, CH, SC or GC in accordance with the soil classification system described in Appendix A of AS 1726. Furthermore, it should conform with the following particle size distribution and plasticity limits: Note: The material classification symbols CL, CI, CH, SC and GC represent clays having low, intermediate and high plasticity, clayey sands and clayey gravels respectively.

TABLE 1 Particle size distribution

AS metric sieve size (mm)	Percentage passing (by dry weight)
75.000	100
19.000	70–100
2.360	40–100
0.075	25–90

TABLE 2 Plasticity limits on fines fraction, passing 0.425 mm sieve

Measure	Score
Liquid limit W_L	30–60%
Plasticity index I_P	>10%

If materials complying with the above plasticity limits are not readily available, clays having liquid limits between 60% and 80% may be used as pad construction material, provided that the pad surface is covered with a layer of compacted gravel (or other approved material), having a minimum thickness of 100 mm, to prevent the clays from drying out and cracking.

Topsoil, tree roots and organic matter must not be used for pad construction. Furthermore, any other material that does not compact properly must not be placed in the pad area.

Wherever non-dispersive materials are available, they are to be used in preference to materials shown to be dispersive using the Emerson test, as described in Method 8.1 of AS 1289.

5.2 Material Suitability/Identification

The visual identification methods described in AS 1726 may be used in the field during construction for determining whether a material complies with the above criteria. However, if there is doubt about the suitability of the material, laboratory testing in accordance with the appropriate sections of AS 1289 should be carried out for confirmation. The administering authority may direct the owner to submit laboratory test results, certified by a soils laboratory accredited by the National Association of Testing Authorities (NATA) or having an equivalent accreditation.

Where the materials available within the general vicinity of the site do not comply with the above criteria, alternative proposals may be acceptable.

6. Correct Moisture Content

All material placed in the pad should be conditioned to have a moisture content within the range of 2% wet to 2% dry of the optimum moisture content required to produce the maximum dry density when compacted in accordance with Method 5.1.1 of AS 1289.

Note: As a guide, the required moisture content for a clay material is as wet as can be rolled without clogging a sheepsfoot roller. A preliminary assessment of the required moisture content of a clay can be made by rolling a sample of the material between the hands. If it can be rolled to pencil thickness without breaking, it should be satisfactory.

In the event that water has to be added to achieve the required moisture content, it shall be added to the borrow area in sufficient time to allow even distribution throughout the material before excavation. To achieve effective water distribution, the surface of the material in the borrow area is to be broken up by ripping prior to watering. Part of the required water may be added to the material following placement on the pad area, but only when it is not possible to add all the necessary water in the borrow area.

7. Compaction

Each layer of material placed in accordance with clause 4 above, shall be compacted to produce either a field dry density of at least 95% of the standard maximum laboratory dry density determined in accordance with Method 5.4.1 of AS 1289, or alternatively, a Hilf density ratio of at least 95% when tested in accordance with Method 5.7.1 of AS 1289.

Note: This degree of compaction may generally be achieved in a clay material by rolling each layer of material, placed at the correct moisture content, with at least eight (8) passes of a sheepsfoot roller of the configuration described in clause 8 below. As a guide, compaction of a clay will generally be sufficient when there is a clearance of 100 mm between the drum of the roller and the compacted material.

8. Sheepsfoot Roller

The following specification describes a sheepsfoot roller which would be suitable for fulfilling the compaction requirements described in Clause 7 above, for the materials specified in clause 5.1:

- The diameter of the drum(s) should be not less than 1 m
- The length of each drum(s) should be approximately 1.2 times the drum diameter
- The feet should extend approximately 175 mm radially from the drum and be of the taper-foot type, with a cross-sectional area close to the outer end of not less than 3200 mm^2 and not more than 4500 mm^2
- The number of feet should be such that their total area close to the outer ends shall be between 5% and approximately 8% of the area of the cylinder that would enclose all the feet (i.e. a cylinder having a diameter equal to the diameter of the drum plus twice the length of each foot)
- The weight of the roller ballasted, should be such that the bearing pressure thus obtained shall be not less than 1750 kilopascals, in accordance with the following formula:

$$\text{Bearing Pressure (kPa)} = \text{Mass (kg)} \times 9.81 \times 1000 \text{ divided by Area of contact of one row of feet (mm}^2\text{)}$$

Rollers of other types and configurations may be used provided that the required compaction is achieved in accordance with clause 7.

9. Test for Adequate Compaction

The administering authority may direct the owner to arrange for compaction testing to be carried out on nominated sections of the pad. Compaction testing is to be performed in accordance with the methods specified in clause 7 of this specification. The test results shall be submitted to the administering authority, following certification by a soils laboratory accredited by the National Association of Testing Authorities (NATA) or a laboratory having equivalent accreditation for the tests performed.

10. Final Trimming

Following the completion of compaction, final trimming should be carried out to produce a smooth, uniform pad surface.

11. Pad Permeability

The procedures specified in this document are designed to produce a maximum pad permeability of 0.1 mm/day. This criteria may be used by the administering authority to ensure that the appropriate environmental protection standards have been achieved.

The administering authority may direct the owner to arrange for permeability testing to be carried out on a nominated section(s) of the pad. Laboratory permeability testing is to be performed in accordance with the methods specified in either Part 6 of BS 1377 (Triaxial Permeability) or Section F7.1 of AS 1289. The test results shall be submitted to the administering authority, following certification by a National Association of Testing Authorities (NATA) accredited (or equivalent) soils laboratory.

12. Alternate Methods

Alternative materials and/or installation methods may produce a suitable pad. Possible examples include the use of synthetic lining materials or soil stabilisation with products such as cement, lime, bentonite, etc., in lieu of clay lining.

Appendix 2: Duty of Care Statement: Spent Bedding and Compost

Aged spent bedding and bedding compost from piggeries are great sources of nutrients for plant growth and carbon for building soil structure. However, like inorganic fertilisers, they need to be spread on suitable areas and applied at sustainable rates to ensure the environment is protected. Those utilising spent bedding or compost must take all reasonable and practical steps to prevent harm to the environment and to areas of cultural heritage sensitivity. Each state has its own Acts detailing duty of care provisions. These typically require:

- Sustainable use of natural resources
- Conservation of biological diversity
- Avoidance of harm to Indigenous cultural heritage.

In particular, spreading of spent bedding or compost needs to be managed to avoid:

- Land degradation (e.g. soil erosion, decline in soil structure, nutrient overloading)
- Odour and dust nuisance
- Surface water and groundwater pollution with nutrients and sediment
- Increased weeds
- Noise nuisance.

To minimise the likelihood of these potential impacts:

- Minimise the risk of spent bedding or compost spillage during transportation by not overfilling the truck and by covering the load
- Where practical, avoid transport routes with a large number of houses close to the road
- Spent bedding and compost should not be stored or spread on areas that are flood-prone. Nor should they be stored or spread on areas where they will pose a significant risk of nutrient transfer to watercourses (e.g. sloping land immediately abutting a watercourse)
- Check the weather forecast before spreading spent bedding or compost and delay spreading if heavy rain is expected or the soil is still very wet following heavy rain. Also check the wind speed and direction to ensure the prevailing wind is not blowing directly towards nearby residences
- Plan to spread spent bedding or compost from mid-morning to early-afternoon when good odour dispersion is likely. Avoid spreading from mid-afternoon to evening. Avoid spreading just before weekends or during holiday periods, particularly if close to a public area
- Determine a suitable spreading rate based on the N, P and K content of the spent bedding or compost, soil properties and the intended land use of the reuse area. The rate should be consistent with the ability of soils and plants grown on the area to sustainably use the applied nutrients, salts and carbon in the spent bedding or compost

- Calibrate the spreader to spread at the target rate
- Monitor reuse areas for weeds and control these if necessary. Although the aging and composting processes can destroy most weed seeds, some seeds may remain viable
- Avoid spreading spent bedding or compost close to sensitive neighbours at night when noise may create nuisance
- Do not allow grazing stock to access stored manure or reuse areas for at least three weeks after spreading.

A recent "typical analysis" sheet for the manure or compost should also be provided to the recipient.

Appendix 3: Manure Valuation Pro-Forma

This appendix provides a method, using the value of nutrients in fertilisers, to place a value on manure nutrients. Farmers looking to use piggery effluent and manure should consider the benefits they expect from reuse. It is important to understand the nutrient status of the soil using testing which will identify which nutrients would be beneficial additions. Not all nutrients added as manure will be immediately available and some may not be fully released for several years after spreading. As well as nutrients, manure contains valuable organic matter which helps to improve soil structure through creation of pore spaces that encourage root penetration and ready movement of water, nutrients and air which in turn assist with the growth of beneficial micro-organisms.

STEP 1: Quantify the Nutrient Content of the Spent Bedding or Compost

The spent bedding or compost should be analysed to determine its nutrient content as this can vary widely in composition.

Analysis of the bedding after aging or composting, rather than immediately after removal from the shed, is recommended as its density, nutrient and moisture content will change during the aging/composting process.

Aged, straw-based spent bedding might contain about:

- 2.0% nitrogen (N) which is equivalent to 20 kg/dry t
- 1.4% phosphorus (P) which is equivalent to 14 kg/dry t
- 2.9% potassium (K) which is equivalent to 29 kg/dry t.

Aged bedding typically has a moisture content (MC) of between 30% and 50%. This needs to be taken into account when calculating the nutrients applied.

With a MC of 40%, the concentration of each nutrient in the aged or composted bedding can be estimated from the dry matter (DM) concentrations using the formula:

Nutrient concentration (kg/wet t) = DM concentration (kg/t) X (1 - (MC%/100))

N	=	20 kg/dry t X (1 - (40/100))		
	=	20 kg/dry t X 0.6	=	12 kg/t or 1.2%
P	=	14 kg/dry t X 0.6	=	8.4 kg/t or 0.84%
K	=	29 kg/dry t X 0.6	=	17 kg/t or 1.7%

STEP 2: Value the Nutrients in Inorganic Fertilisers

It is possible to put a worth on the N, P and K in spent bedding or compost using the value of these nutrients in inorganic fertilisers. Table 1 shows the typical composition of a range of common fertiliser products. Commercial, bulk, delivered fertiliser prices were obtained for common N, P and K fertilisers. These were $550/t for urea, $800/t for triple superphosphate and $800/t for muriate of potash (Nov. 2012). These were used to calculate the values for N, P and K given in Table 1.

- Since urea is 46% N and costs $550/t, N can be valued at $1.20/kg (i.e. ($550/t / 0.46)/1000).
- Triple superphosphate contains 20% P and costs $800/t. The P in triple superphosphate is worth about $4/kg (i.e. ($800/t / 0.2)/1000).
- The K in muriate of potash is worth about $1.60/kg (i.e. ($800/t / 0.5)/1000).

Thus, for this exercise, N is valued at $1.20/kg, P at $4/kg and K at $1.60/kg.

TABLE 1 Nutrient value per kilogram in common inorganic fertilisers

Nutrient	Fertiliser	Price	Nutrient content %	Nutrient value ($/kg)
Nitrogen (N)	Urea	$550	46%N	N = $1.20/kg
Phosphorus (P)	Triple Superphosphate	$800	20% P	P = $4.00/kg
Potassium (K)	Muriate of Potash	$800	50% K	K = $1.60/kg

STEP 3: Apply the Fertiliser Nutrient Values to the Nutrients in Spent Bedding or Compost

The nutrient values ($/kg) for N, P and K calculated in Step 2 can be multiplied by the N, P and K in the spent bedding or compost (from Step 1) to obtain a macro-nutrient value for the product. Table 2 provides an example for spent bedding.

Greater accuracy can be obtained by using site-specific data for the composition of spent bedding or compost and up to date fertiliser prices.

TABLE 2 **Value of nutrients in aged spent bedding based on prices for common inorganic fertilisers (in Table 1)**

Parameter	Nutrient concentration* (kg/wet t)	Value# ($/kg nutrient)	Value of nutrients in spent bedding ($/t)
N	12	$1.20	$14.40
P	8.4	$4.00	$33.60
K	17	$1.60	$27.20
TOTAL			**$75.20**

* from Step 1 # from Step 2

Important points to remember when looking at these results include:

- The nutrients are only of value if they are needed in the cropping system. For instance, if the crop requires N and P but the soil already has ample K, the latter provides no additional value. Hence, in this case, the value of the spent bedding or compost value is driven by the summed value of the N and P but not the K
- This valuation process does not include the contribution of other elements like sulfur, zinc, calcium, magnesium, boron, copper and other trace elements that may be very valuable to the cropping system depending on the soil nutrient status. However, if these are deficient, their value can be be added to the macro-nutrient value using the same steps. Spent bedding and compost also add carbon to the soil. This helps to improve soil structure and water-holding capacity and reduce its erosivity. However, it is difficult to put a dollar value on these benefits
- N losses after spreading must be considered. If the manure is not incorporated into the soil immediately, losses could be significant with a corresponding reduction in the value of the N contribution by the spent bedding or compost
- The benefits from the nutrients contained in spent bedding and compost may be realised over several years due to the rates of nutrient availability. For example, only one-third of the N in the compost might be available in Year 1, however, this varies considerably. P availability also varies widely between soil types. The end result is that the value of the spent bedding or compost could be spread over 2–3 years as nutrients become available to plants
- Spent bedding and compost do not supply nutrients in the ideal ratios for plant needs. They are often best used in conjunction with an inorganic fertiliser program designed to meet plant requirements. One option is to apply the spent bedding or compost at a rate that meets P requirements and then supplement the N with a conventional fertiliser to meet additional crop needs. An alternative is to apply the manure or compost at a rate that meets crop N requirements although this is only acceptable if testing demonstrates that the soil is able to store the surplus P. If this option is chosen, N availability in the first year needs to be carefully considered to avoid the risk of N deficiency. Storage of P in the soil must be regarded as a temporary measure. The stored P should be removed by growing and harvesting crops before additional spent bedding or compost is applied to the land.

STEP 4: Calculate the Value of the Nutrient Applied

The value of nutrients applied as spent bedding with an application rate of 5 t/ha are shown in Table 3. The value is determined by multiplying the value of each nutrient ($/t) by the spreading rate (5 t/ha).

TABLE 3 Value of nutrients applied as spent bedding

Nutrient	Nutrients applied* (kg/t)	Value of nutrients applied# ($/t)	Nutrients applied @ 5 t/ha (kg/ha)	Value of nutrients applied @ 5 t/ha ($/ha)
N	12	$14.40	60	$72.00
P	8.4	$33.60	42	$168.00
K	17	$27.20	85	$136.00
Total value	–	**$75.20**	-	**$376.00**

* from Step 1 # from Step 3

STEP 5: Determine the Net Benefit of Spreading the Manure

Table 4 provides the net benefit of using spent bedding, taking into account all the costs of carting and spreading, compared to the calculated value of the nutrients contained in the bedding.

TABLE 4 Net Benefit of nutrients applied as spent bedding accounting for all costs

Item	Cost per t ($/t)	Total cost at 5 t/ha ($/ha)
Cost of bedding	$8.00	$40.00
Carting and spreading	$36.00	$180.00
Total cost	$44.00	$220.00
Value of nutrients applied*	$75.20	$376.00
Net benefit of using spent bedding	$31.20	$156.00

* From Step 4

In this example, there is an economic advantage of about $156/ha in applying 5t/ha of spent bedding compared to applying equivalent rates of nutrients using triple superphosphate, muriate of potash and urea.

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